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TECHNOLOGY TRANSFER CONFERENCE

December 8 & 9, 1986

THE SHERATON CENTRE
TORONTO, ONTARIO,
CANADA

Part E
Environmental Economics

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TECHNOLOGY TRANSFER CONFERENCE

December 8 & 9, 1986

The Sheraton Centre

External Research Projects

PART E
ENVIRONMENTAL ECONOMICS

Organized by
Research Advisory Committee

Sponsored by

Corporate Resources Division
Ministry of the Environment
Ontario
CANADA

Goal Statement

"To achieve and maintain a quality of the environment - including air, water and land - that will protect human health and the ecosystem and will contribute to the well-being of the people of Ontario."

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INTRODUCTION

The Ontario Ministry of the Environment holds its annual Technology Transfer Conference to report and publicize the progress made on Ministry-funded projects. These studies are carried out in Ontario universities and by private research organizations.

The papers presented at the Technology Transfer Conference held in December 1986 are presented in Conference Proceedings. These Proceedings are divided into five parts corresponding to the conference sessions dealing with:

Part A: Air Quality Research ;
Part B: Water Quality Research;
Part C: Liquid & Solid Waste;
Part D: Analytical Methods; and
Part E: Environmental Economics.

This part is a collation of those papers presented at Session E of the Conference.

For further information on any of the projects, the reader is kindly referred to the Principal Investigators or to the Research Management Office at (416) 965-5788.

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THE ROLE OF ECONOMICS IN ENVIRONMENTAL MANAGEMENT

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It is doubtful that there exists an area of public policy in which a clearer case can be made for the necessity of interdisciplinary approaches to problem analysis and policy design than the area of environmental quality management. Yet this case is regularly ignored on both sides of the line dividing economics from other relevant disciplines, including the life, chemical, and physical sciences, other social sciences, and certain of the humanities. It often seems as if each individual discipline is convinced it can tell society what its environmental goals ought to be and how those goals ought to be achieved. There is fault enough on all sides of this situation -- and I certainly do not exempt my own discipline from that statement. But the purpose of this paper is not to apportion blame; rather it is to catalog the contributions that economics, in cooperation with other disciplines, can make to environmental policy. In the process, I shall indicate a few places where I believe economists have gone astray by failing to work with other specialities. But if a major message of this paper is intended to be a call to economists to cross disciplinary lines, I hope no one misses the flip side -- it is equally silly for engineers or biologists or medical doctors to think that they have a singular hold on social welfare and that economists should only be called in at the end, to estimate the costs of the proposed policy and judge whether or not firms "can afford it."

Indeed, it is worth making one more preferatory point, obvious to some, perhaps heretical to others. None of the scholarly disciplines, alone or in combination, can tell society what it ought to want by way of an environmental quality goal, or even by way of management techniques to obtain a given goal. The most we can do is to point out the implications of a variety of possible

choices of goals and management techniques, including implications for all parts of the environment; for costs, international competitiveness and job displacement; for health and comfort; for the value of recreation; for our self-image as a society; and so on.

All that said, let me proceed to a brief catalog of the potential contributions of economics. I believe that those contributions may be subsumed within three broad areas:

- critically examining often conflicting claims about the need for any government policy (or conversely, about the desirability of "deregulation")
- estimating the costs and benefits associated with and predicting the indirect effects of particular policies -- either before or after implementation -- as an input to the decision process
- analyzing implementation problems, and designing positive and negative incentive systems, and accompanying monitoring and enforcement activities.

The Need for Public Policy

It is worth starting here because our democratic societies seem to swing with alarming rapidity between two extreme views. One is if we find anything at all not to our liking, government regulation must be the answer. The other is that any perceived social problem can be solved by some ingenious definition of rights and creation of a market in those rights. The best role for the economist, in my opinion, is that of skeptic, demanding that the would-be regulator make a technical case for intervention; and being equally tough on the marketeer, asking for the reasoning that makes him or her think a market can work.

That role as skeptic is founded on some powerful welfare theorems based on strong assumptions, and on trenchant analysis of when the assumptions can be expected to be invalid -- when the theorems should fail. The relevant theorem for environmental policy concerns says that, in the absence of complications, the competitive market reflecting the optimizing behavior of individual consumers and producers can lead to a situation in which no one can be made better off without someone else being made worse off -- a Pareto optimum in the jargon of the trade. This result, the "invisible hand" of Adam Smith, rests on the existence of prices for goods, services, land and savings, that are faced equally by all participants in the market and that carry, in remarkably efficient summary form, information about the desires of individuals and capabilities of technology. Economists with a keen appreciation for the difficulty of obtaining and transferring that information in ways dependent on a central agency, begin with a predisposition to opt for markets where opting is possible.

But what are the "complications" referred to above? Again, confining myself to matters most germane to environmental management, I will concentrate on one: the existence of public goods. Such goods are those like sunsets, national defense, and ambient air quality, that we all share willy nilly. My consumption -- as a viewer of a sunset, a protected citizen, a breather of air -- does not, in the normal course of events -- interfere with your consumption of the same amount of each public good. Two of us or two hundred or two hundred thousand can all consume the same sunset, the same security and the same air quality (the latter with qualifications that need not detain us). Indeed, it is difficult, if not truly impossible, to prevent those resident in the area in question from enjoying a sunset, breathing the same quality air, and so forth.

Public goods need not be free; national defense costs money. They need not be provided by the government; a fireworks display involving rockets provides a public good to people away from the site at which the rockets are touched off and to which admission might reasonably be rationed by a private person or firm. Nor are all government-provided goods public in this technical sense. The Post Office provides an intrinsically private service which I can easily be prohibited from enjoying if I don't pay.

The problem with public goods is that the decentralized price system cannot deal with them. If we could calculate the optimum amount of air quality in a region, we could not obtain a price to charge potential consumers of the good that would make each person desire to consume just that optimum amount. In principle, we could obtain, by dint of great effort, individualized prices so that each individual would be charged a price consistent with him or her wanting the socially optimal quantity. But of course it is difficult in any case to charge a price, individualized or common, for a public good. In summary, the price system, and hence the market, fail "by existence", as a great expositor of these results put it.

Thus, if the "invisible hand" welfare theorem gives economists a predisposition to favor market solutions, the existence of public goods in such policy areas as environmental quality should give them pause in recommending market-like solutions to environmental problems. For example, consider the suggestion that we should simply define marketable permits to discharge pollution, thus creating property rights to be traded, and let the resulting market determine environmental quality. Those who want higher quality (lower discharges) than provided for in the initial offering of rights can, it is claimed, combine to purchase and retain rights. Aside from technical problems having to do with possible concentration of rights on a few hands resulting both in cartel-like price power and environmental "hot spots",

the prescription deserves intense skepticism because no sub-group of individuals can either determine or pay for the socially optimal amount of pollution control.[1] Such a system would not be adjustable in the higher quality direction except by further government intervention. Similarly, privatizing wilderness makes no sense so long as the public good, knowledge of wilderness preservation, has value to non-users of wilderness areas.

There should be no need to belabor the point: economists have tools available for evaluating arguments about and prescriptions for government intervention in or private market solutions to environmental problems. In their analysis they will be informed by other specialists such as atmospheric and aquatic scientists and even psychologists, who can illuminate the conditions determining whether particular environmental services are public goods or not.

THE COSTS, BENEFITS AND RELATED EFFECTS OF PROPOSED POLICIES

While public goods foul up markets, they are still worth something to consumers of them. The trick is to find out how much those consumers would be willing to pay for environmental improvements. Environmental public goods, such as improvements in air quality, cost something, in real resource terms too. And while cost estimation is generally agreed to be conceptually easier than benefit estimation, it is by no means trivial, especially not when what is being costed is a change in ambient environmental quality.

[1] It is worth pointing out that pollution discharge is conceptually a private good, access to which can be priced and rationed so that a desired total amount can be achieved through a common price applied to all dischargers. On the other hand, the spatial distribution of discharges is, in general, germane to the ambient quality level experienced at different points in a region, so to obtain a given spatial distribution of desired quantities, discharger-specific prices are required. Further, the ambient quality produced by the combination of discharges and natural environmental action, is a public good. Citizens, as consumers of air quality, not discharges, have to deal with the public good problem.

Other effects not captured by resource costs or estimated willingness to pay may be important to policy makers as well. For example, displacement of jobs from high sulfur coal mining in one region to low sulfur coal mining in another region has been a vexing dimension of SO_2 emission control policy in the U.S. Economists can provide information in all these areas with suitable cooperation from other disciplines.

This is clearest in the case of benefit estimation, so let me concentrate on that problem and leave the others with the brief assertions of the previous paragraph. But first, let me observe three things. One: even if aggregate and marginal costs and benefits could be perfectly estimated, that would not say that benefit-cost analysis should be the basis for social decision-making about environmental quality or anything else. There are deep ethical questions here about how to deal with individual welfare in the absence of actual payment of compensation; and the benefit-cost criterion is but one answer. More to the point in actual decision-making, political reality involves complex balancing of group interests in the presence of inflexibility in the distribution of both benefits and costs. That means cost-benefit analysis can never be more than one input to the process.[2]

Two: I am not claiming that benefit estimation is even a necessary part of environmental policy-making. If society collectively decides that benefit estimation should not be done, it is certainly possible to make policy on the basis of discussions about costs and physical effects — ambient concentration changes, visibility improvements, fish population changes — and costs. This does tend to result in each regulator and politician supplying

[2] It is a required input now in the U.S. under President Reagan's Executive Order 12291, which requires the preparation of C-B analyses for all major regulatory decisions, even where the existing legislation says that such analyses can play no role in the decision.

his or her own ad hoc estimate of benefits, but that is ultimately what politics requires anyway.

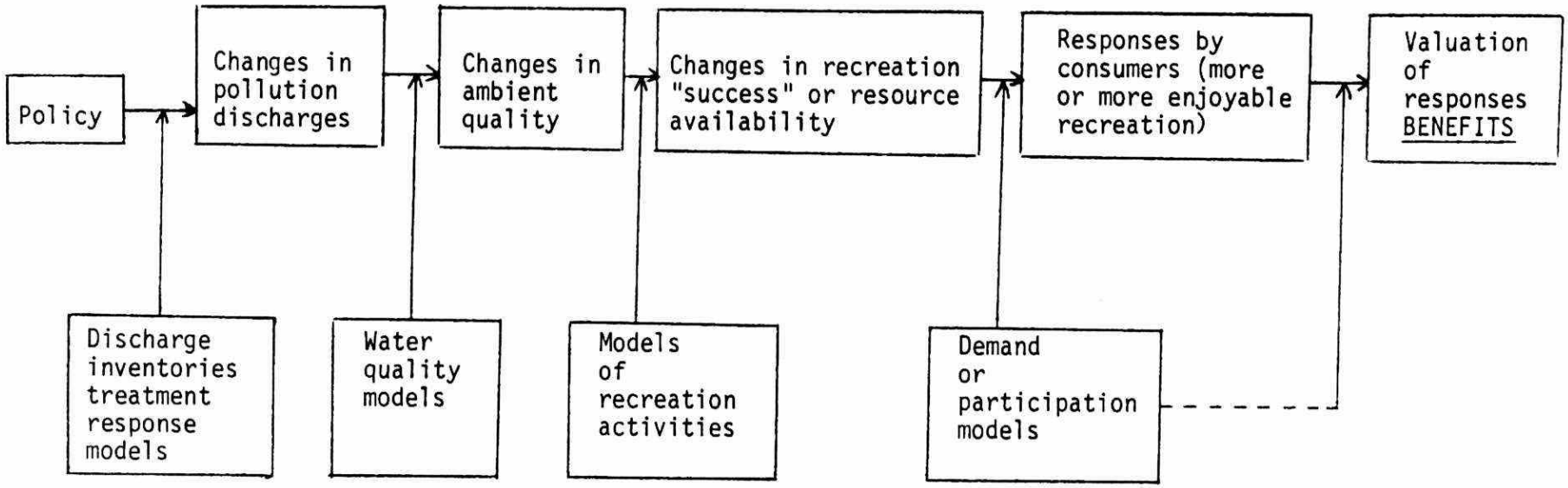
And three: I believe that in the current state of the art, we can supply only highly aggregated and imprecise estimates for part of the benefits of any particular environmental policy. But what we can accomplish today is vastly more than we could accomplish 10 years ago. With wise investment of research and development funding I believe we could see as much improvement again in the next 10 years. By 2000, benefit estimation for environmental policy-making may be worthy of being taken quite seriously indeed.

To see why benefit estimation is hard, it is necessary to understand what is involved in doing it. One way of setting out such an understanding is in terms of "linkages" -- those connections between the parts of the puzzle necessary to turning a particular policy description into a benefit number (or range of numbers, more properly).

As one among many possible examples, let me describe the set of linkages for understanding water-based recreation benefits. This is laid out schematically in figure 1. Notice that we must know about pre-policy discharges and how they will change; what these changes in discharge levels will do to water quality; how the "objective" changes in water quality are viewed by different categories of recreationists; how those views translate into responses in the sense of leading to more or less enjoyable activity; and how these changes in recreation behavior are valued.

This is a formidable menu of "musts", and it turns out that in <u>every case</u> we lack the data and models to do the job as it should be done. The following is a brief description of what is and is not available.

FIGURE 1
From Policy to Benefits:
Linkages to be Understood



For discharges we have perhaps the best information; yet it displays large elements of approximation and inference. A massive point source inventory that exists at Resources for the Future (RFF) has been extended to include inferred loads of nonpoint pollutants from various source categories. This is a version of an inventory maintained by the U.S. Environment Protection Agency (EPA). But even this inventory is based in large part on rules of thumb rather than measurement.

Predicting how the policy will change discharges is sometimes easy, sometimes difficult. The easiest policy to deal with is one of required percentage reductions; the hardest -- that applying to soil erosion, for example -- is one based on "best management practices" where the results cannot be precisely estimated. In between lie the technology-based point source standards, such as "best available technology," which are translated into discharge requirements by reference to model or average plants in particular categories. (Such projections for point sources are possible in the RFF inventory referenced above.)

Estimating how discharges affect water quality and how quality affects recreation is difficult given the state of the art in natural systems modeling. As a practical matter, estimates are often restricted to the relationship between biodegradable material and instream dissolved oxygen (DO) levels. There are two problems here: one is predicting how the aquatic system will react to pollutants in any terms. The second is finding measures that relate both to discharges and to recreation. For example, DO is one indicator we can link back to discharges, and it can be linked forward to fish survivability, clearly relevant to recreational fishing benefits. But DO is not, except at its extreme low end, linked well to boating or swimming decisions. The appropriate indicators for these activities may include turbidity, oil and grease, microorganism counts, and floating solids. These

indicators are not now routinely predictable with acceptable confidence by state-of-the-art water quality models acting on discharges. Thus, benefit estimation waits on work by sanitary engineers and aquatic biologists on improved water quality predictive models.

Benefits are generated when consumers get increased enjoyment from the same spending (of time and money), spend less for the same enjoyment levels, or spend more and obtain more. The problem here is that these responses are not, in the natural course of things, recorded; nor are these changes linked in any easily recordable way to particular changes in water quality. To illustrate these points, if one French restaurant in a city changes its menu or decor or chef, the results, if there were any, would be recorded in its sales volume and number of meals served. (Enhanced enjoyment per meal would not be recorded. Only if higher prices could be charged and the same volume maintained could we infer such an effect. Otherwise, direct interviews would be necessary to acquire such information.) In another example, if the Potomac River just above Washington were clearer on average throughout the year, there would likely be an adjustment by area fishermen to substitute the Potomac for more distant waters or increase the frequency of their outings or just enjoy each Potomac outing more. None of these effects would be observed, however, without a substantial special data-gathering exercise.

Even when some special effort is made to gather data on what recreationists do, the assembled information typically does not include the prices recreationists are paying to do these things. The actual recreation experience is usually unpriced, and what people pay is largely bound up in necessary complementary goods, such as boats for boating, or spent in the form of travel costs (direct and travel time values).

In these circumstances, values attached to changes in recreation-related water quality must almost always be inferred from indirect evidence. In the best possible situation, data would be available for individuals on the set of travel cost prices for alternative sites, the activities facing each, and the resulting "purchase" of activity days by place and activity. These data would, of course, be in addition to the usual income and related data. From these data, demand functions for days of the activity would be estimatable. Such functions would immediately yield well understood approximations of the benefits of changes in the set of travel cost prices implied by increases in availability of activities due to pollution discharge reduction.

More commonly, the best that is available are data on participation by individuals in the activities of interest without either travel cost prices for possible places or information on where the individuals actually did go. Work on recreational fishing benefits generally reflects these limitations.

It is possible to approximate average (or expected) travel cost by using an inverse function of the density of suitable -- including suitability by virtue of being unpolluted -- water areas. An average travel cost proxy can then be attributed to each individual for a region or jurisdiction, with participation being related to this and other variables. Changes in participation because of changes in availability, due in turn to discharge reductions from pollution control, can then be projected. Because the real travel cost prices are not available, the money welfare measure (the benefit) of changes in behavior does not fall directly out of what is estimated. Rather, a two-stage process must be used: first, projecting changing participation in, say, activity days; and second, producing separately a value per day, perhaps from a completely different source. The pitfalls of such a strategy have been described elsewhere. Suffice it to say here that

simulation studies show that such a method can give results that are off by more than 100 percent or can, on the other hand, comport very well with the "true" results. Unfortunately, in real cases, we cannot know which situation applies.

Other methods of benefit inference are also possible, including one based on the purchase of complementary goods. In boating, for example, data on ownership is the most extensive and detailed available; data on boating activity exists only for much smaller samples. It must be stressed that in all actual cases of indirect inference, we face data that are substantially poorer than those required for the "best" situation. In particular, in no case I know of have the necessary travel cost prices been available. Beyond that, the quality of the price proxies is bound to be suspect because of the dearth of even baseline data on water quality in recreation-related terms. For example, in a recent study of the pollution control benefits accruing via swimming, boating, and marine recreational fishing, the analysis had to fall back on a survey of state officials that asked for their judgments about the extent to which water areas were unavailable due to pollution.

Thus, at the heart of the benefit estimation procedure are several data gaps that are expensive to plug, have not been plugged in the past, and are unlikely to be in the future. The upshot is that as a practical matter we can have only limited faith in the results of "classical" recreation benefit studies, <u>even when</u> the policy being considered comprises all pollution control activities.

There is an alternative to part of the tricky chain of inference set out above. This is the direct, or willingness-to-pay-survey, or contingent valuation technique. As the several names suggest, the method amounts to asking people what they would be willing to pay for specified changes in the level of environmental services (public goods, remember) connected to

particular policies. Economists have traditionally turned their noses up at this method because of the incentives people can be shown to have to misrepresent their preferences. But recent research seems to me to show that these incentives are not important enough in the survey setting to make it worthwhile for people to think through the complicated problem of how they ought to lie. It is easier to try to tell the truth. In the long-run this method of obtaining directly estimates of willingness to pay seems to me to be the most promising item in the benefit estimation armory. But in the context of this paper's stress on the multidisciplinary character of the environmental problem it is worth noting that this method requires much non-economic input. None of the linkage in figure 1 except the last is really avoided by using contingent valuation methods, if we want to ask reasonable questions linked in meaningful ways to real policy alternatives. In addition, the art of designing surveys is one in which economists are not normally trained. They need help from disciplines such as sociology and psychology if they are to have survey instruments that have any real chance of producing what is intended.

Implementation of Environmental Policy

This is an area in which a tremendous amount of ink has been spilled by economists over the years. Because of the disciplinary fascination with decentralized prices and market efficiency, there have been a series of attempts to show how an administered price system (effluent or emission charges) could solve all, or at least a good part of, society's environmental problems. This ingenuity has also been directed to the idea of marketable permits to pollute. Most recently, economists have taken an interest in monitoring and enforcement as a part of whatever implementation scheme is adopted.

While I am critical of the classical literature in this corner of environmental economics, I believe useful contributions have been and in the future can be made by economists if they are careful to inform themselves of the relevant technical features of the problem. Thus, the early fascination with uniform emission charges followed from a grounding in classical economic theory without a corresponding appreciation for the importance of location in determining a source's contribution to a regional environmental quality problem. As pointed out above, when location differences are taken into account, uniform charges cannot be used to achieve static economic efficiency (least cost for given ambient results). Indeed, it can be shown that they are not even the best of the second best implementation methods.

But later analyses of implementation have not only recognized the technical problem raised by different source locations in a complex environment, but have also gone beyond static efficiency considerations to take into account a wider area of criteria for judgment. For example, it has been recognized that such criteria as the following are relevant:

- Flexibility in the face of a changing economy. Thus, administered prices must in principle at least be recalculated when anything changes -- an old source is shut down or a new one opens, a process change occurs that lowers one source's marginal abatement curve -- if static efficiency is to be maintained beyond the initial period.
- Dynamic incentives. Economists have shown how "ratcheting down" of discharge standards as technology improves, as provided for in U.S. water pollution control legislation, can destroy the incentive for undertaking research aimed at that improvement. Thus, far from aiming the system at zero discharge, ratcheting down may condemn it to stagnation with existing technology.

- Consistency of monitoring and enforcement capabilities with implementation scheme design. Thus, for example, if we regulate or charge for discharges per unit time, we must be able to measure such discharges and have a means to do so often enough and precisely enough to present the source with a credible threat of being found in violation if actually violating permit terms or cheating on charge payments.

The last point, on monitoring and enforcement, deserves special emphasis because in the past economists have done so little with it. For the most part, the literature on charges and standards has assumed compliance and derived the static economic implications of that assumption under the different instruments of policy. But a discipline based on an assumption that actors pursue their self-interest could hardly be content with assuming costly compliance would occur. As one examines the alternative in any particular situation, it becomes clear that useful advice requires knowledge of the applicable law, of available measurement technologies, and of statistical tools for deciding when a violation has occured. Further, environmental problems differ in the character of the polluting act and hence in the nature of monitoring. Keeping track of the discharge of SO_2 from a smokestack in a known and fixed location is one thing. Making sure that barrels of spent dry cleaning fluid end up in the right place and not in the woods is quite another. In the one case a marketable permit might have many advantages; in the other a positive incentive such as that provided by a deposit-refund system might be more to the point.

Thus, technical knowledge of specific environmental problems must go hand in hand with economic ideas about incentives for static efficiency and dynamic change and with recognition of the administrative costs of inflexibility.

Over all, the design process can usefully be informed by ethicists and political scientists, who can analyze and sometimes help to mitigate features that are political liabilities.

Concluding Comment

This has been a selective survey of the potential contributions of economists to the ongoing debate about environmental policy -- choice of goals as well as of implementation methods. The message I hope the reader will take away is that these contributions are substantial and socially valuable but that economists will never reach that potential operating alone. Only in the context of multidisciplinary approaches can their insights and tools be really useful.

ABATEMENT COST FUNCTIONS

THE "WORKHORSE" OF ENVIRONMENTAL MANAGEMENT

BY

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ABATEMENT COST FUNCTIONS - THE "WORKHORSE" OF ENVIRONMENTAL MANAGEMENT

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1. Introduction

To many people, environmental economics primarily concerns two issues: the cost of environmental protection activities and whether such costs will have severe economic repercussions on employment or on particular firms, industrial sectors or regional economic activity. Media reports about environmental affairs invariably cite cost estimates of proposed abatement programs with little explantation or qualification. Such cost estimates are often obtained from firms which are faced with abatement requirements and who may claim that compliance costs will cause severe economic disruptions. In such instances, cost estimates are sometimes overstated and so must be verified.

On the other hand, environmental criteria and guidelines have sometimes been promulgated without explicit consideration of the costs of achieving them. Environmental requirements of this nature, as well as technology-based abatement objectives such as "best available technology," imply that unlimited amounts of money should be devoted to pollution control and environmental protection.

In a society that must satisfy its needs from limited resources, one cannot devote all available funds to a single purpose. Procedures and criteria must be established to allocate available money and efforts among competing uses in order to produce the range of goods and services (including free public goods) that are most desired and valued by society at large. However, in order to allocate funds efficiently and fairly to environmental protection activities, information about the costs of achieving different requirements and objectives is absolutely essential.

Moreover, properly defined and delineated cost data, or estimates of expected costs, are essential for making informed and rational choices concerning environmental policies, programs and abatement activities. Such information can be used in a variety of ways to design programs, predict reactions to regulatory initiatives, assess impacts and to set environmental objectives

Dewees (December 1976) discusses the kinds of abatement cost data or estimates that are needed for effective decision-making with respect to environmental production activities . He argues that the best information one could have would be a schedule of costs to achieve all conceivable levels of emission controls for any given industrial plant or polluter.

Estimates of the range of costs that would be incurred to achieve different levels of emission reduction are far more useful for policy deliberations than single-valued cost figures. These ranges of costs, together with their associated emission reductions (or final emission levels), are called abatement cost functions. Because there are so many analytical techniques, issues and questions that require this information or that can be assessed by it, abatement cost functions can truly be called the "Workhorse" of environmental economics.

The purpose of this paper is to review some efforts here in Ontario that have been made to generate and use the kind of cost data or estimates suggested by Dewees. In doing this, the key theoretical concepts that define abatement cost functions will first be reviewed. The functional forms in which abatement cost information can be presented will be discussed along with an explanation of how abatement costs functions are related to traditional production cost functions.

Methods and approaches for deriving empirical abatement cost functions will then be catalogued. A set of computer programs which was developed by staff at the Ontario Ministry of the Environment, and which can be used to generate empirical cost function information, will be described briefly.

Several specific examples will be cited which illustrate how empirical abatement cost functions have been derived and how they might contribute to Ministry of the Environment regulatory choices and decisions. These example will highlight specific uses that can be made of this information including determination of least-cost abatement programs for specific polluters, setting defensible environmental objectives, making explicit environmental-economic trade-offs, assessing financial impacts on firms who are subject to abatement requirements, evaluating the consequences of different enforcement policies, anticipating the reaction of a firm or a municipality to abatement requirements and the development of "affordable" abatement programs and schedules for specific polluting establishments.

The paper will conclude with some comments about the availability and accuracy of data needed to generate abatement cost functions together with some suggestions as to how to assemble these data. Further research and applications of abatement cost analyses in the Ontario context will also be noted.

2. Production and Cost Functions - Theory and Concepts

Individuals strive to maximize their satisfaction or utility from the goods and services which they buy or use (including free public goods). Firms endeavour to maximize profits from the goods and services they sell. In its simplest form, profit is equal to revenues less costs. In a competative market economy where prices are determined exogenously,

firms generally only have control over their costs. Similarly, public agencies and governments usually have less control over their revenues than they do their costs. Consequently, both public and private agencies make efforts to minimize their costs in order to achieve cost-effective operations and (in the case of private firms) maximize profits. Information and data on the cost are, therefore, critical to the effective and efficient operation of an agency or an enterprise.

Costs are generally perceived to be the value of the inputs used in a productive process or activity. These inputs include the raw materials, machinery, equipment, labour, energy, interest, admistration and, for private individuals or companies, a minimum return on investment. These **accounting costs** are compared with outputs or revenues and are used to make production and investment decisions. Market prices and wage rates of the various inputs generally provide reliable measures of their value to society.

However, costs should be viewed in a much wider context. When resources or inputs are put to certain uses, the benefits they could yield in other uses or applications are irretreivably lost. Opportunities to produce other goods or services or to gain other kinds of utility and satisfaction are foregone. Consequently, economists refer to the **opportunity costs** of producing goods or implementing a project. The distinction between accounting and opportunity costs is important in certain circumstances. For example, some foregone benefits or opportunities, such as swimming or recreational fishing that may be precluded by pollution, are not normally marketed so that prices are not available to determine their value. Although those who cause pollution do not have to bear these social costs, their private accounting costs are less than the total opportunity costs of the polluting activity to society. Opportunity costs may also diverge from accounting costs when there is substantial unemployment or when there is monopoly pricing of factor inputs.

In its efforts to minimize costs and maximize profits, a firm must face two key questions:

- how much output should be produced?

- what combination of inputs should be used to produce any given quantity of output?

The level of output is determined by comparing the prevailing market price with the incremental or **marginal cost** of producing extra units of output. Marginal cost is defined below. Profit is maximized when a firm produces output so that the marginal cost of the last unit of output is just equal to the market price or the extra revenue it receives from the same unit of output.

The second question is answered by mixing inputs so that the largest

amount of output is produced at the lowest cost possible. This is accomplished by following a relatively simple rule. Costs of producing given levels of output are minimized when the ratios of the extra output of each unit of input (eg. labour, raw material etc.) to the price of the input are equal. This rule is also satisfied when the marginal costs of each input factor are equal. This test is easier said than done but it provides a rule for cost minimization that can be applied to any sort of production process for which appropriate cost data are available.

The extra output that can be produced with an extra unit of any of the necessary inputs is determined by means of a production function. This is nothing more than a schedule of outputs that can be produced by specified quantities of variable inputs.

The accounting costs to which an enterprise (or for that matter a government agency) is subject include **fixed costs** and **variable costs**. Fixed costs are those expenses that must be incurred whether or not something is being produced. Variable costs are the quantities of variable inputs (eg. labour, raw materials, etc.) times their unit prices.

Three different cost measures are generated and used in cost analyses:

- **Total cost** = total fixed plus total variable costs for a specified quantity of output.

- **Average cost** = total cost divided by quantity of output.

- **Marginal cost** = increase (or decrease) in total cost divided by the increase (or decrease) in output. This is the same as the change in total cost resulting from an increase or decrease in output by one unit.

The production function specifies the physical quantities of inputs needed to produce an output. Cost functions convert these physical quantities to measures of monetary value such as dollars per unit time or net present value terms.

It is exceedingly rare that there is only a single technical option or level of effort that can be applied in a particular pollution situation. Consequently, there is a generally a range of different levels of pollution control or environmental protection that can be achieved at different costs. For any given level of abatement or final emissions, there is one combination of technologies or options that is least-cost. It is understood that an abatement cost function consists of only those least-cost points.

In general, costs increase with increasing degrees of abatement (or declining levels of emissions or "pollution intensity"). The relationships between total abatement costs and final emissions and between marginal costs of abatement and final emissions are depicted in Figure 1. These

relationships are contingent upon existing technologies and their compatabilities for combination. This particular functional form also assumes a constant design capacity for the particular technologies.

Figure 1 implies that total costs of abatement increase gradually over a particular range of final emissions. As one attempts to remove the final quantities of contaminants or emissions, costs rise rapidly to the limits of the available technology. Marginal costs, which are the first derivative of the total cost function, are zero when total costs do not change; constant at some positive amount when total costs increase at a constant rate; and rise when total costs increase at an increasing rate. Information about the shapes of the marginal and total cost curves for a particular pollution source can be extremely useful to the assessment of an abatement program and the design of appropriate objectives and policies to achieve them. Dewees, Everson and Sims (1975: 80-90) analyse these relationships as well as relevant optimization conditions in some depth.

A cost function alone does not provide sufficient information to determine a socially desirable emission limit or objective (however this might be defined). Other information such as discharge or ambient concentration objectives or the value of the benefits of different levels of final emissions would be needed to make such choices. For example, in order to achieve a level of pollution control that is broadly "efficient", abatement should proceed to the point where the value of the extra (eg. marginal) benefits are just equal to the relevant marginal costs.

Cost functions can, however, be used to determine the least expensive combinations of controls and abatement when there are two or more sources at a given location and the resulting emissions are perfectly mixed so that they do not cause differential effects (Dewees, Everson and Sims, 1975:20-24). Abatement is achieved at the lowest overall cost when each source controls its emissions to the extent that their marginal costs of abatement are equal (Dewees, Everson and Sims, 1975:29-31; Downing, 1984:76-79). This is analogous to the marginal condition for minimizing production costs in a firm noted earlier.

The concept of equating marginal costs and benefits is useful even in cases where neither benefit nor cost curves are precisely specified. Estimates of a few points on either curve, or even general ideas of shapes and magnitudes, can help design rational policies and programs (Dewees, December 1976:6). In fact, one could interpret the "best available technology" requirement as economically efficient if marginal benefits were reasonably constant over a wide range of abatement and if the "best available technology" is interpreted as lying just below the sharply rising portion of the marginal cost curve.

3. Empirical Estimation Procedures

Empirical studies of abatement costs are invariably restricted to accounting cost items. The cost catagories generally consist of capital in vestment, operation and maintenance (O&M), interest or capital charges and, in some cases, land and installation charges. Capital costs, land and installation charges are one-time costs whereas O&M and interest are recurring costs, generally on an annual basis. These capital and O&M costs are incommensurate measures and cannot be legitimately summed. In many instances, only capital costs are cited. But annual O&M and other costs can constitute a significant proportion of the total costs incurred over the life of an abatement system.

If O&M and other annual charges are expected to be constant (other than for inflation) over the life of the system, then capital costs can be "annualized" with an appropriate amortization algorithm and added to O&M to yield a typical or average annual cost. This figure can then be compared with similar estimates of other systems or options. If O&M costs are expected to change significantly over the life of the system or if new equipment will have to be installed during the planning period in question, then future costs are discounted and summed together with the initial capital expenditure to yield a net present value (NPV) which can also be compared with estimates for other options or systems.

Empirical abatement cost functions can be divided into three methodological groupings (Dewees, Everson and Sims, 1975:94). **Engineering studies** define in detail the necessary equipment and related costs for a particular technology or to achieve specified abatement objectives. This approach is often the source of single-valued cost estimates. The second method utilizes **statistical or econometric** techniques. Equations are identified and estimated using data on existing facilities to estimate coefficients with linear regression techniques. The third method, termed the **systems analysis** approach, attempts to combine all feasible abatement technologies and systems in a programming framework to determine the least-cost set of abatement programs.

Over the past 10 years, personnel in the Ontario Ministry of the Environment have developed a set of computer programs which can be used to generate empirical abatement cost functions for ranges of abatement levels at individual industrial plants. Called the **WAste Treatment Analysis Program** (WATAP), it best classified as a "systems analysis" technique. WATAP consists of two "Steps." "Step 1" is a program which will:

- identify all combinations of treatment technologies that can be implemented at a plant. Each combination of one or more

technologies is called a **Plan**;

- incorporate specified technical incompatibilities so that only those combinations of technologies that are technically feasible are specified.

Step 2 consists of a set of programs which use the results from Step 1, plus other data, to:

- calculate the expected reductions in each pollution parameter, the final emissions and the timing of these reductions, for each Plan;

- calculate the capital and the total net present value of all costs and revenues associated with each abatement Plan over a user-specified planning period (eg. 20 years);

- calculate the effects of each Plan on the company's cash flow and the Provincial Government's tax receipts;

- calculate the cost per unit of emissions removed or reduced.

Step 2 can also sort the feasible Plans, of which several hundred may be identified for a single industrial plant, from lowest to highest emissions or from lowest to highest cost. The WATAP can also extract the set of Plans which will achieve successively lower levels of emission reduction at the lowest cost (or highest net revenue). This is the least-cost set of Plans and constitutes an abatement cost function.

Each Plan is independent of each other. Thus, in order to achieve a specific reduction in emissions, one would implement the least-cost Plan that would achieve the desired reduction. However, one cannot subsequently "add on" another Plan in order to reduce emissions further. The treatment technologies that make up each Plan can, however, be implemented consecutively or concurrently.

The WATAP uses plant-specific data concerning pollutant loadings at each outlet, abatement technologies, abatement efficiencies, costs and compatibilities among technologies. Various kinds of economic and interest rate data are also required.

The WATAP generates a net present value estimate for each Plan over the user-specified planning period. Because costs and revenues are escalated each year to reflect inflation and any expected changes in relative prices of inputs or recovered by-products, nominal rather than real interest rates are used in discounting and in calculating loan interest payments.

The relevant cost and final emissions estimates from the least cost

set of Plans is a total cost function. Theoretically specified marginal costs cannot be calculated from WATAP estimates. However, an average cost per unit of pollutant removed can be calculated which can be used to compare abatement Plans and costs among different plants. Since the present value figure that is used as the numerator in the ratio is based on costs (and revenues, if any) over the entire planning period, the reduction in emissions that is achieved over the same period should then be used as the denominator in the ratio. Moreover, this ratio can be calculated only on the basis of one emission parameter at a time. Comparisons of these ratios can indicate which of several plants can reduce its emissions at the lowest cost.

Some of the input data and assumptions made in specific applications are often uncertain. For example, treatment efficiencies could be higher or lower than those used in the analysis. Moreover, cost estimates for each treatment technology could be higher than anticipated. Using the WATAP, re-estimations of the costs and emission reductions resulting from each Plan can be made with different input data or assumptions.

In the sections to follow, applications of the WATAP and other techniques will show how empirical abatement cost functions have been generated and how this information has been used to conduct various types of analyses and assessments that may be required in regulatory decision-making.

4. Empirical Abatement Cost Studies in Ontario

4.1. Inco-Falconbridge Task Force

In May of 1980, an Ontario/Canada Task Force was established to investigate and evaluate air pollution (especially sulphur dioxide or SO_2) abatement technologies and options for the nickel and copper smelters operated by INCO Ltd. and Falconbridge Nickel Mines Ltd. in Sudbury. Sulphur emissions have been a long-standing problem from these sources and, while steady reductions in total emissions had greatly improved the ambient air quality conditions in and around Sudbury, further reductions were thought to be required to address the long range acid depostion problem.

Although provincial SO_2 emission reduction targets had not been established at that time, it was nevertheless recognized that any commitment to reducing acid deposition must include abatement at the Sudbury smelters.

Absence of specific emission targets for the smelters in the Sudbury area, together with the large number of possible abatement technologies that could be implemented by these sources, made the analysis of potential process changes and abatement programs a formidable task. Even when the technologies to be considered were limited to those which

would require no more that five years of development work to determine their effectiveness, hundreds of potential permutations and combinations of technologies were possible. Moreover, even when potential programs were identified, it was not clear which ones were most desireable.

In order to come to grips with the practical difficulties of focussing the large number of potential abatement programs into a policy-relevant context, the WATAP was applied. The number of potential abatement technologies were further restricted so that the number of potential programs that were examined were reduced substantially. Using WATAP results to determine the least cost set for each smelter, the number of programs in the least cost set was reduced from 54 to 8 in the case of INCO and to 5 in the case of Falconbridge (Ontario /Canada Task Force, Fall 1982:ch. 8).

The analyses revealed that at least one abatement program for INCO, which basically involved installing new smelting technology, would result in a positive return on investment, in present value terms, while reducing emissions. Further SO_2 emission reductions would impose absolute costs on the corporation.

The Task Force commissioned other studies on the financial capabilities and prospects for the two companies, trends and forecasts for nickel and copper markets and the degree to which regional employment and income are dependant on INCO and Falconbridge. This information, together with cost estimates generated during the course of the study, enabled the Task Force to determine the potential economic impacts of specific levels of abatement at the two smelting operations.

The Task Force did not recommend final emission reduction targets for either smelter (Ontario Canada Task Force, Fall 1983:Letter of transmittal). However, in December 1985, the Ontario Government announced a major program called **Countdown Acid Rain** (Ontario Ministry of the Environment, c.1985) which established a schedule of emission reduction objectives for the major SO_2 emitters in the Province, including INCO and Falconbridge. The information developed by the Task Force was undoubtely useful in the development of emission objectives and timetables for the Countdown program. INCO officials also appear to have revised their own estimates of the costs of achieving the relevant SO_2 objectives in light of the Task Force findings.

The Countdown program also requires periodic reporting by the relevant firms on progress being made toward the abatement objectives, including revised cost estimates of abatement projects to be initiated. Just as monitoring emissions and ambient environmental quality is necessary to judge progress on meeting goals, so too the monitoring of past and future costs of these actions is becoming an increasingly important aspect of program management and evaluation.

4.2. Acid Deposition Screening Model

A basic problem in developing a stragegy to reduce acidic deposition is to determine how much emission reduction overall should be achieved and how much each individual source should reduce its own emissions within this context.

Formulating and evaluating strategies for reducing acidic deposition can be an arduous task because of the large number of precursor pollutant emitters and the numerous approaches and criteria that can be used to allocate possible emission reductions among relevant emitters. For this reason, abatement strategy development was critically in need of a procedure to identify and "screen out" the most desireable options from the hundreds of potential configurations of abatement within the relevant geographical region. To this end, an analytical procedure was developed which reduced the number of possible policy options by identifying those strategies which are both efficient in terms of minimizing overall SO_2 control costs and effective in terms of achieving the desired deposition objectives.

A linear-programming based Screening Model was developed for the Ministry of the Environment (Edward A. McBean & Associates, September 1983). The procedure utilizes data from 235 large point-source SO_2 emitters as well as so-called "area" sources and "background" deposition to calculate the change in acidic deposition at 20 specific "receptor areas" that results from specific abatement configurations. For each of the 235 emission sources, SO_2 emission levels are specified along with estimated removal efficiencies and costs of control technologies. Total costs for a technology were calculated as the sum of capital costs and the present value of annual O&M costs incurred over a 20-year period. Prior to being utilized in the linear programming procedure, a sub-model caculated a least-cost abatement function for each major source (Edward A. McBean & Associates Ltd., October 1983) . Figure 2 shows a plot of the cost-removal combinations and the least-cost abatement curve for a Canadian power plant.

Screening Model runs produced estimates of the total annualized costs of abatement for given strategies or configurations. The linear programming procedure could determine the least cost configuration of abatement to achieve specific deposition loading targets, or lower, at each of the receptor areas in eastern North America. These results are discussed in Edward A. McBean & Associates (September 1983) and Castel and Griffith (forthcoming).

The results of the Screening Model were presented to various interprovincial and intergovernmental committees and work groups, including Ministers of the Environment, in the course of developing provincial and Canadian positions on abatement objectives for acid rain.

After reviewing the results of the Screening Model, provincial Ministers of the Environment endorsed the principle of achieving deposition objectives in the most cost-effective manner. This principle implied that some provinces, particularly Ontario, would have to undertake a disproportionate share of the abatement effort because its sources tended to be nearest some of the most sensitive receptors. The Screening Model also clearly indicated that abatement in the US would be necessary to achieve the target deposition levels of 20 kg. per hectare-year in all receptor areas.

4.3. Evaluation of Economic Incentive Policies

An aggregate abatement cost function was derived by Peat, Marwick and Partners (July, 1983) for SO_2 emitters in Ontario. This cost function was generated to help evaluate existing and proposed policy instruments that are intended to induce firms to implement required abatement programs. The policies examined include the existing Command and Control regulation and enforcement system augmented by **surety deposits** and **non-compliance (delay) penalties**, **Effluent charges**, and **Transferrable emission rights schemes**.

The analysis incorporated the major industrial emitters of SO_2 in Ontario. Because the three fossil fuel power plants are under common ownership/management (Ontario Hydro), these sources were "bubbled" and analytically treated as a single emitter. Similarly, the 8 petroleum refineries were combined as a single "bubbled" emitter because their total emissions are relatively small and the abatement technologies that could be applied in each plant were identical. Using a computer program, the authors calculated the least cost combination of "strategies" (eg. combination of technologies) that would achieve successively lower levels of SO_2 emissions for the 3 combined power plants and the 8 combined refineries.

Using relevant cost and abatement efficiency data, total cost functions for each emitter were derived. These emitter-specific cost curves were step functions which implies that costs are constant over the emission reduction range of a particular abatement strategy. Cost functions for each of the five "emitters" are summarized in Table 1. Costs are exoressed in total annual **private** and **social costs**. Private costs refer to after-tax costs incurred by an individual emitter. Social costs, in the context of the present study, are before-tax costs which reflect the total costs to society of the abatement program regardless of who incurs the costs.

The same algorithm used to "bubble" the power plants and refineries was then employed to determine least cost combinations of strategies that are listed in Table 1 and to construct the aggragate abatement cost

curve shown in Figure 3. Annualized social costs (eg. before-tax costs) are plotted on the vertical axis. Each point on this curve indicates a specific combination of emitters and their relevant technologies or strategies. "Tonnes of SO_2 reduced" are plotted on the vertical axis. The origin of the graph (0 tonnes abated) represents the total base (1980) emission level or 1,530,000 tonnes per year.

This minimum aggregate cost of abatement curve is then used to determine the excess cost of not implementing a least cost combination of emitters and abatement technologies. An aggregate abatement cost function is meaningful in this context because acidic depostion is the chief concern. Sulphur dioxide emissions are thus perfectly mixed in the atmosphere before they are deposited as acid rain.

Four command and control scenarios were assessed first. These included pro-rata reductions or cutbacks of 18%, 50%, 67% and 75%. Each of these regulatory scenarios resulted in excess annualized costs ranging from $120 to $400 million (Peat, Marwick and Partners, July 1983:Exhibit VI-1). For example, in order to achieve a 67% pro-rata reduction, emitters would be required by their available abatement technologies (Table 1) to reduce their emissions by 1,238,000 tonnes per year rather than the necessary 1,021,000 tonnes per year. The total costs to achieve this level of abatement would amount to $818 million per year. However, if reductions were orchestrated so as to minimize total costs, the total cost that would result is read from the cost function in Figure 3 as $418 million per year. The pro-rata cutback approach would, therefore, impose an extra $400 million cost on society that is theoretically excessive.

Under an emission charge scheme, a charge rate of $954/tonne of SO_2 would have to be levied to induce emitters to implement abatement sufficient to achieve a 67% reduction in emissions (Peat, Marwick and Partners, July 1983:Exhibit VI-2). A charge would induce this abatement because each emitter would have to pay more in total charges on reduced emissions without abatement than the total of abatement costs plus charges on reduced emissions after abatement. The total before-tax abatement costs incurred would amount to $496 million per year; only $78 million in excess costs rather than $400 million.

Emitters would have to bear private (after-tax) costs of $317 million for abatement plus $413 million in emission charges for a total of $730 million per year (Peat, Marwick and Partners, July 1983:Exhibit VI-3). The $730 million in private cost is higher than the estimated $537 million that emitters would have to bear under the pro-rata cutbacks. However, $730 million is lower than the $818 million that would otherwise be imposed on society.

There is a distributional difference in the two policies as well. Under the pro-rata cutbacks, all of the costs of abatement would be directed to suppliers and installers of the relevant pollution control equipment. Under

the emission charge scheme, only $496 million would be spent of the purchase and installation of abatement facilities. The remainder, $413 million, would constitute transfers to government coffers.

Similar analyses were presented for the transferrable emission rights scheme. However, the authors note that, because of the small number of emitters involved, a competitive market for emissions rights is not assured. Moreover, to the extent that the abatement cost functions used in the analyses reflect reality, market participants would likely be willing to buy or sell rights only in "chunks". This could impose a barrier to the implementation of this policy because there could be a mismatch of buyers' requirements and sellers' offerings in terms of both price and quantities (Peat Markwick and Partners, July 1983:VI-12).

These and other analyses of economic based policy instruments have not resulted in any major changes in provincial or federal government regulatory approaches with respect to the environment. The only recent innovation of which the present authors are aware and to which the Peat,2 Marwick study made some contribution is a proposed amendment to the Ontario Environmental statutes. This amendment would give the Ministry of the Environment the discretionary authority to require that a polluter deposit financial security at the outset of an abatement program. This security, which could be in the form of cash, a letter of credit, a surety bond or other negotiable securities, would be returned when required abatement systems are installed. The security deposit would, however, be at risk of forfeiture if agreed-to deadlines were missed. In this way, the deposit would provide a financial incentive to complete abatement programs on time which is otherwise absent with respect to existing enforcement instruments. At this writing (fall 1986), the amendment was in the process of final drafting and review prior to introducion to the Provincial legislature.

4.4. WATAP Assessment of Lime Plants

Air quality studies by the Ministry of the Environment in 1981-2 found that particulate emissions from three limestone quarry and manufacturing operations in Southwestern Ontario caused exceedances of point-of-impingement criteria specified in Regulation 308 of the Ontario Environmental Protection Act. Ministry abatement orders (eg. control orders) were developed to indicate to the plants how much abatement would be required and on which particular outlets in the plants. In the course of developing these control orders, a comprehensive evaluation of the various control options was carried out using the WATAP.

Relevant data on particulate emissions from each outlet in the plants, abatement technologies and their compatibilities, abatement efficiencies and costs and installation times for abatement techologies were assembled. A nominal discount rate of 15% was used in calculating

the emission charge scheme, only $496 million would be spent of the purchase and installation of abatement facilities. The rest, $413 million, would constitute transfers to government coffers.

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Relevant data on particulate emissions from each outlet in the plants, abatement technologies and their compatibilities, abatement efficiencies and costs and installation times for abatement techologies were assembled. A nominal discount rate of 15% was used in calculating

terms. However, in order to increase abatement from 68% removal to 68.5% removal, costs would almost triple.

Clearly, the Plan which achieves the 61% reduction in particulates is the start of the range of rising marginal costs. One would expect that the firm in question would begin to protest if the Ministry required that particulates be reduced by more than 61%.

The Plan which would achieve the maximum reduction of 68.5% can be interpreted as the Best Available Technology (BAT) since the technologies included are available and they achieve the maximum emission reduction possible short of closing the plant. There is little doubt, however, as to the reaction of the firm if BAT was required in this instance. It is not apparent how one might define Best Practicable Technology in the context of these cost functions since all of the technologies and Plans are considered to be "practicable." As noted earlier in the paper, additional information would be needed to determine the specific abatement objective.

Several other decision criteria can be specified to set emission objectives, including fairness, balancing benefits with costs or achieving ground level concentration criteria for particulates (Regulation 308) at least cost.

Quantitative information on the benefits of specific levels of abatement are not generally available. Fairness can be defined in many different ways. For example, requirements can be specified to achieve equal final emissions at each plant, equal abatement expenditures at each plant, an equal absolute reduction in emissions at each plant or an equal percentage reduction in emission at each plant.

A comparison of the equal percent reduction is indicated on Figures 4, 5 and 6. First of all, a 50% reduction in emission would be impossible for plant B to achieve although it would cost plant A about $700,000 and plant C about $1.6 million to do so, in present value terms. An equal expenditure of, say, $1 million each would yield a 61% particulate reduction by plant A, 22.5% reduction by plant B and a 37% reduction by plant C. Actually, plant C would only have to spend about $600,000 to reduce emissions by 37% or it would have to spend $1.5 million to achieve a 40% reduction.

At this writing, dispersion modelling had not been completed which would indicate which level of emissions would be required for each plant to meet the point-of-impingement particulate concentration guidelines. If such calculations are based on individual plants, the plant-specific cost functions can be used to determine which Plan would achieve the required emission levels at least cost. If perfect mixing of the particulates is assumed, then an aggregate least cost function can be constructed from the WATAP results and least cost combinations of plants and Plans can be determined.

Once an abatement or emission reduction objective is decided upon, the cost estimates of the least cost Plan can be used to assess the

economic impacts of the Plan on the firm or establishment.

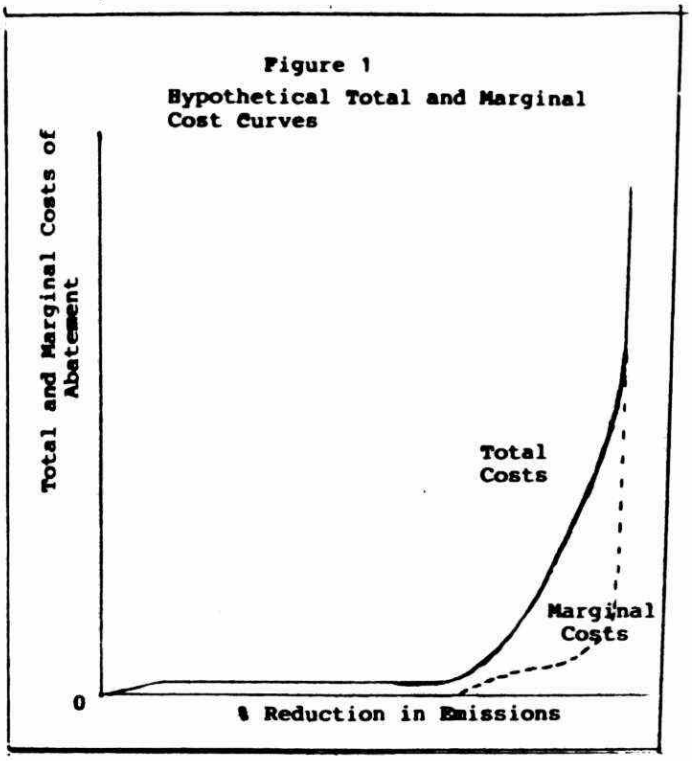
The information presented in the abatement cost functions and which were used in generating these graphs have obvious uses and advantages to agency personnel during the negotiation for abatement programs. This particular exercise also had a potential benefit to the firms involved. In its submissions to the Ministry, plant B specified its prefered program. The WATAP results indicated that other Plans could be implemented which would achieve the same particulate reductions for the less money or, for the amount of money that the company was willing to spend, Plans were identified which would achieve a greater degree of abatement. These insights were incorporated into the control orders that were finally issued to the plants.

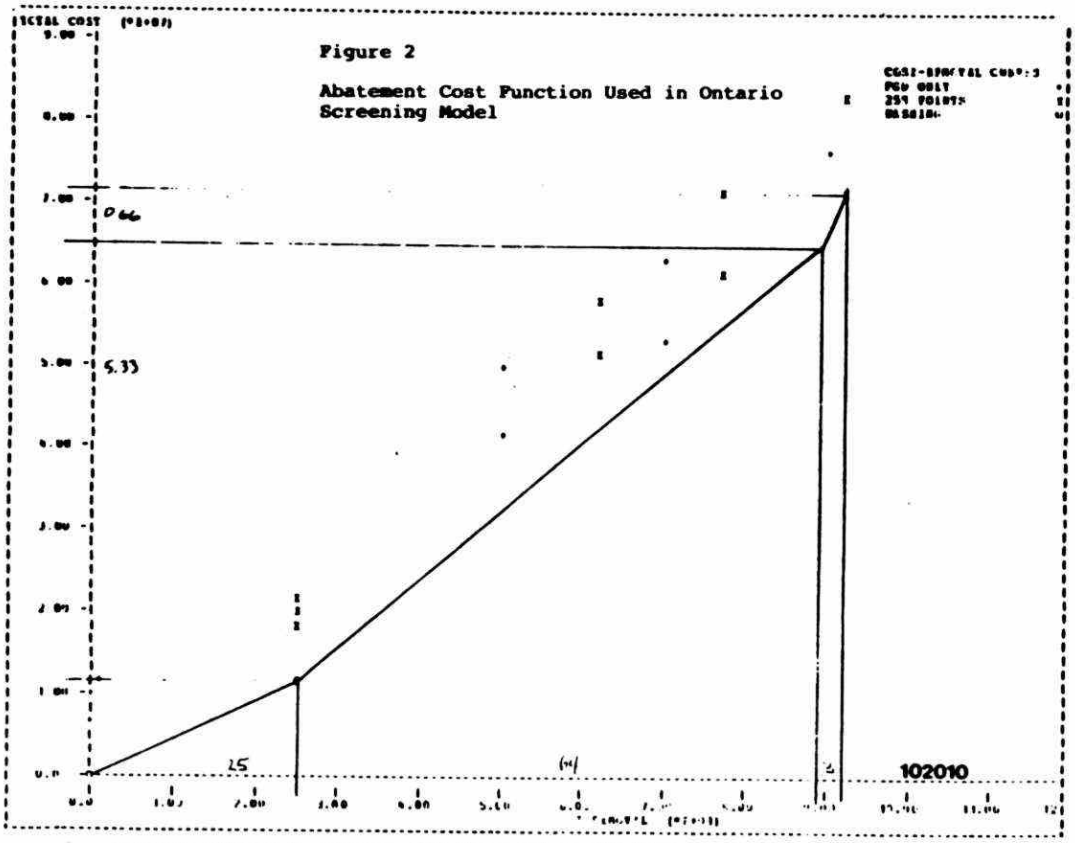
5. Conclusions and Future Work

The work presented in this paper has focussed on cost functions for individual establishments using engineering estimates of the relevant technologies and their costs. Little effort has been made to assemble actual abatement cost data to verify cost estimates or to generate statistical abatement costs functions. Clearly, studies of this nature could yield some very interesting and potentially useful results. Such studies could also improve the accuracy of the cost estimates generated by tools like the WATAP.

However, in many pollution control and regulatory situations, a high degree of accuracy is not critical. We need only get an idea of the range of gradually rising costs as were illustrated in the lime plant example and the approximate location of any discontinuities or large increases in cost for a small gain in abatement to help in designing control programs. Cost information can also be used in negotiations with firms who claim that the cost of compliance will be excessive and damaging to them.

These analyses are, however, data intensive and time consuming. They should not be applied accross the board in an uncritical manner. However, for major initiatives such as the Municipal-Industrial Strategy for Abatement (MISA) or the Great Lakes Remedial Action Plans, the systematic derivation of relevant cost functions and their use in evaluations and assessments can help ensure that these programs are implemented in manner that is fair, efficient and, perhaps most important of all, effective in acheiving the program goals.





Source: Edward A. McBean and Associates Ltd (October 1983)

Table 1

SUMMARY OF ABATEMENT STRATEGIES AND ASSOCIATED COSTS
(INCLUDING BUBBLES)

SOURCE	ANNUAL BASE EMISSIONS (000 TONNES)	ABATEMENT[1] STRATEGY	ABATEMENT (000 TONNES)	REMAINING EMISSIONS (000 TONNES)	TOTAL ANNUAL COSTS ($000,000 1982) PRIVATE[2] TOTAL $	PRIVATE[2] $/TONNE ABATED[4]	SOCIAL[3] TOTAL $
Inco	812	0	0	812	0	-	0
		1	306	506	20	65	48
		2	629	183	61	97	151
Ontario Hydro (Bubble)	377	0	0	377	0	-	0
		1	85	292	81	953	96
		2	159	218	153	962	177
		3	240	137	229	954[5]	284
		4	339	38	390	1150	486
Algoma (Wawa)	143	0	0	143	0	-	0
		1	61	82	12	197	26
		2	122	21	21	172	46
Falconbridge	122	0	0	122	0	-	0
		1	107	15	6	56	15
Refineries (Bubble)	77	0	0	77	0	-	0
		1	15	62	15	1000	29
		2	29	48	30	1034	59
		3	41	36	59	1439	120

1. As noted in the text, a ZERO or no abatement strategy (represented by 0) is included for each source. This is necessary in the analytical work when considering aggregate abatement strategies over all emitters, in which some emitters do not reduce emissions.

2. "Private" costs refer to after-tax costs incurred by individual emitters.

3. "Social" costs refer to before-tax costs and reflect the total costs to society regardless of their incidence, or distribution.

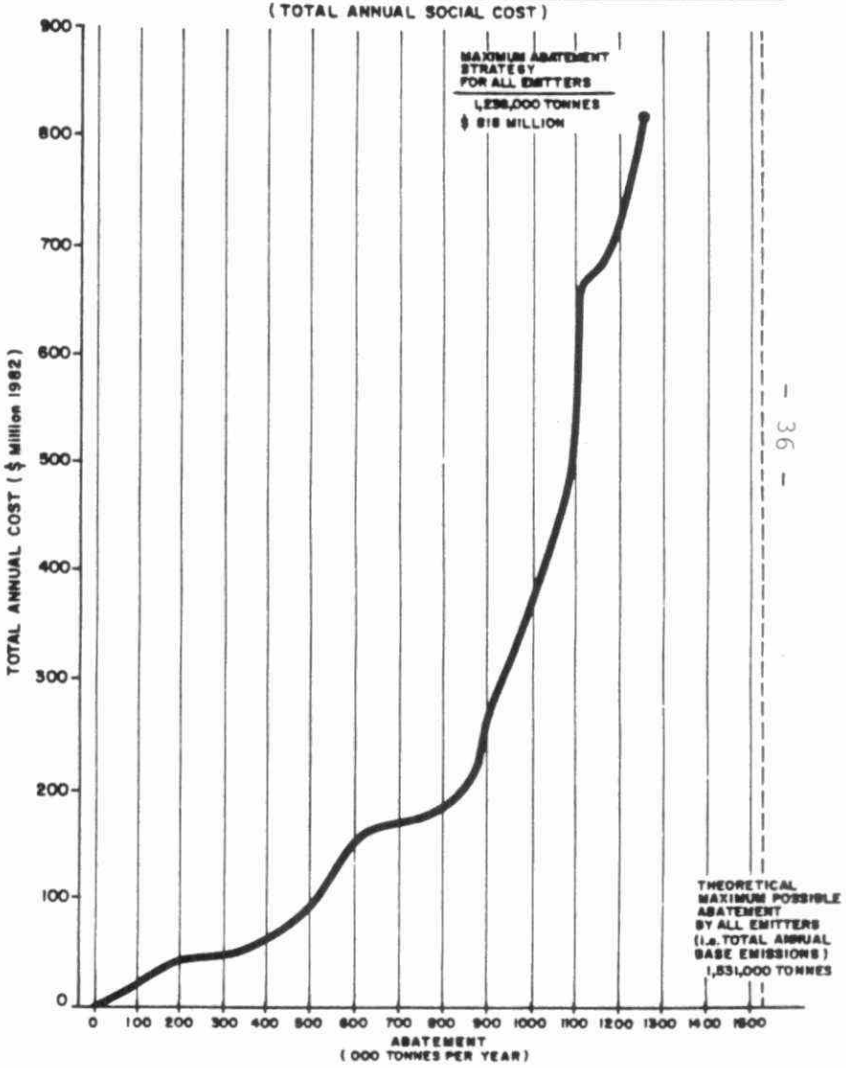
4. We have not included the pulp and paper mills for analysis in this report. On the basis of data from the Ministry, the annual cost per tonne abated is approximately $500 to $600 on a private cost basis.

5. Within the accuracy of the cost data provided, strategies 1, 2 and 3 for Hydro could be considered the same in terms of average cost per tonne abated.

Source: Peat, Marwick and Partners (July, 1983:Exhibit V-4)

Figure 3

MINIMUM COST OF ABATEMENT CURVE FOR ALL EMITTERS AS A GROUP



Source: Peat, Marwick and Partners (July, 1983) Exhibit V-5

NOTE

FIGURES 4, 5 and 6 WERE UNAVAILABLE AT TIME OF PRINTING

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Measuring Social Costs of Electrical Exports and Cost Recovery Opportunities of Environmental Pollution Control at Ontario Hydro

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1.0 INTRODUCTION

Electrical energy production from fossil-fuel generation provides significant benefits to the people of Ontario which are tempered somewhat by impacts to the environment. These potential impacts to society are, in turn, partially compensated by the re-cycling and re-use of environmental byproducts created during combustion. This paper will review the social costs resulting from fossil generation used to provide export to the United States and will also list the value of re-usable products resulting from environmental controls and which bring a benefit to Ontario Hydro customers.

The National Energy Board of Canada require us to provide evidence, in our application for electrical export license, that the price charged would recover an appropriate share of all costs, including social costs, incurred in Canada. These social costs, resulting from emissions due to fossil-fired electrical export sales to the United States, are a cost component of Ontario Hydro pricing agreement. In 1986, this social cost value is established at 0.04 cents/kilowatt hour or one to two percent of the overall price. This report will outline procedures for assessing potential environmental impacts and calculating social costs.

In addition to this cost recovery, Hydro also has policies concerning the sale of by-products of their operations. Presently markets have been found for the sales of ash from fossil-fired stations, cobalt 60 from nuclear reactors, timber from right-of-ways and waste oils from all facilities. Markets are being sought for tritium, deuterium and waste heat sales. These private benefits will be highlighted in the latter part of the report.

2.0 SOCIAL COSTS OF ELECTRICAL EXPORTS

Before granting an electricity export license, the NEB must satisfy itself, at a public hearing, that the price to be charged is "in the public interest." Part of the evidence submitted by Hydro in this regard relates to recovery of the appropriate share of the costs

incurred in Canada, including social costs. At one such hearing in 1973, Ontario Hydro argued that there were no social costs since its submissions were meeting the regulation for "point of impingement concentrations" in accordance with the 1971 Ontario Environmental Protection Act. Further, Ontario Hydro contended that Ontario Regulations were consistent with the objectives of the Federal Clean Air Act. Intervenores suggested that the social costs were measurably large and that Ontario Hydro export energy sales were not recovering these high social costs.

The NEB approved a two-year export license which strongly recommended that for the next set of hearings in 1976, Hydro should prepare and present results of social cost studies.

In 1974, Hydro commissioned external consultants to carry out literature surveys to assess potential environmental impacts and damage costs in six areas: health, buildings, clothing, Great Lakes affects, vegetation and animals and property values.

Table 1 briefly outlines the results of the studies and the social cost estimate.

These series of consultant reports were the first useful contribution to the understanding of the social effects of atmospheric emissions in which damage estimates were to be recovered. As a result, for the purpose of pricing export energy from fossil-fired sources in Ontario [Lakeview and Nanticoke Thermal Generating Stations (TGS)], the social cost of emissions in Canada was estimated at between 0 and 0.31 cents/kilowatt hours (1986$).(1) The mid-point of this range was established as the actual pricing value.

In 1979, Ontario Hydro again applied to the NEB for an export license. The same six receptor categories were reviewed by external consultants except the Great Lakes effects were expanded to include impacts on inland lake water quality. They came up with little that was new in the area of effects. However, they did find that between 2 and 4.2 percent of the total acid deposition in Ontario lakes could be related to emissions from Hydro's TGS. The social cost component was estimated at between 0 - 0.05 cents/kilowatt hour (1986).(2) This range was less than the 1974 value by a factor of ten, due to new research information and improved calculation methodologies. Different from 1974, the maximum value was used for pricing.

In 1982, Ontario Hydro, Production Branch, formed a Social Cost Steering Committee to oversee all future studies. In 1984, this

Committee decided to update the consultant studies, this time using internal resources only. Only five areas were reviewed:

1. Health effects.
2. Aquatic ecological systems.
3. Terrestrial ecological systems.
4. Building materials.
5. Property values.

Hydro's export license is valid until 1991. However, Hydro does review these social costs periodically and if necessary revise the social cost value. This most recent reassessment of the literature and calculated social cost is reviewed in detail below.

2.1 Results of the 1984 Social Cost Update

The object of the 1984 review was to update the 1980 consultant report on the effects and social costs of air pollution produced or influenced by fossil-fired emission due to export generation. Attention was focused on acid gas emissions levels for 1982 and forecasted for 1986 and 1989.(3) For ease of presentation only calculations to 1986 will be presented. Social costs for other years will vary according to deposition levels and escalation values.

Human Health - Literature Review

The human health literature review(4) covered: epidemiological studies of air pollutants (long-term or irreversible health effects), controlled human studies (short-term effects), and animal studies (biological mechanism of a certain response). Furthermore, human exposures to indoor air pollutants were also assessed.

The main pollutants assessed for health effects were SO_4, SO_2, NO_x, particulates, polynuclear aromatic hydrocarbons (PAH), radionuclides and trace element emissions, total sulphate and nitrate aerosols, and acid deposition. Health effects were extended beyond the "normal" segments of the population to effects on "sensitive" groups such as people with chronic obstructive pulmonary diseases, the very young, the elderly and subjects with reactive airway diseases (eg, asthma).

Also included were the effects of deeper penetration and greater inhaled volumes of air pollutants in exercising subjects.

Current medical and epidemiologic studies indicated that:

- SO_2, by itself, is an atmospheric constituent at present ambient concentrations. However, SO_2 may be associated with mortality at levels much higher than the current US primary standard. The results concerning respiratory effects of SO_2 on asthmatics and people with normal responses at concentrations in the range of 0.1 to 4.0 ppm, are mixed and contradictory.

- The levels of NO_2 in Canada are relatively low and the present standards seem adequate to protect human health.

- There is no direct evidence of adverse effects of sulphate (SO_4) on humans at current US ambient levels - 25 $\mu g/m^3$, an order of magnitude higher than those registered by the Ontario Hydro monitoring network.

- Statistical studies conducted for broad segments of the US urban population (macroepidemiological studies) provided indirect evidence of a weak but potentially significant relationship between air pollutants (SO_4 and TSP) and human health.

- The contributions of radionuclides, trace metals and organics to the atmosphere from fossil-fired generating stations are insignificant.

- Current medical and microepidemiologic literature indicate that acid deposition presents no direct health problems. There is no information on the contribution of acid rain to the changes in concentration of contaminants in drinking water. It appears that acid precipitation has not affected groundwater to a measurable extent in sensitive receptor areas in Ontario.

Human Health - Social Cost

Two independent methods, based on macroepidemiological studies by Lave and Seskin(5) and Freeman(6) were used to estimate health and social costs even though there is no direct evidence to link emissions and increased health costs. The macroepidemiologic literature indicates the potential existence of a weak but statistically significant relationship between air pollutants and human health. Elasticity* estimates, which include the dose/response relationship between air pollutants (SO_4 and TSP) and human health, were used to generate a mortality and morbidity

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*Elasticity - Unit free number that represents the expected percent change in mortality or morbidity rates associated with a doubling of the mean pollution value.

social cost range for Lakeview, Nanticoke and Lambton TGS (within 30 km) and the remainder of Ontario. The calculation formula is outlined in Appendix 1. Table 3 summarizes the overall social costs for 1986.

Table 3

Range of Health Social Costs

[Cents/kW.h of fossil exports (1986$)]

Station/Region	Year 1986
Lakeview	0-0.015
Nanticoke	0-0.005
Lambton	0-0.005
Ontario (beyond 30 km of TGS)	0-0.066
Total Range	0-0.090
Most Likely Value	0.031

Aquatic Ecosystems - Literature Review

The aquatic study [7] reviewed the effects of air pollutants, primarily the acid precursors, SO_2 and NO_x, on the aquatic environment: water quality, bacteria and fungi, primary producers, invertebrates, amphibians and fish. Little evidence exits to suggest that photochemical oxidants (ie, ozone), trace organics (eg, PAH's), radionuclides or trace metals resulting from fossil-fired emissions have significant effects on the aquatic environment.

Acidification of lakes can result from long-range transport of acid gases, natural processes such as water table fluctuations, chemical weathering, natural inputs of organic acids and watershed management activities (logging, farming, etc).

Reduction in lake pH and alkalinity and subsequent increases in heavy metals can affect lake decomposition processes, species diversity and composition of aquatic biota. Fish populations are mainly affected by reproduction failure but can also be affected through direct mortality, reduced growth, selected deformities, and heavy metal uptake.

Aquatic Ecosystems - Social Costs

The primary social costs associated with atmospheric deposition in the aquatic environment are related to the sport fishing industry. Commercial and subsistence fisheries as well as other forms of

aquatic recreation were neglected since these fisheries were either primarily centred in non-sensitive areas or areas of negligible deposition due to export power, of relatively low economic value or not seen to be affected substantially by acidification.

In calculating losses to the sport fishery the sensitive areas of Ontario receiving deposition from exported power were approximated for the Ontario Ministry of Natural Resources (MNR) regions of Algonquin, Northeastern and Northcentral. Based on alkalinity data published by the Ontario Ministry of Environment[8] the proportion of lakes in each region susceptible to acidification was determined and the time to acidify for those lakes was calculated based on projected deposition data with and without the export of power.[3] Since the hydrogen ion loading rate in the Northcentral Region did not exceed 50 $meq/m^2/yr$, the level at which lake acidification was assumed to occur, it was assumed that the lakes in this area would not acidify from long-range transport. Fishing expenditure and participation data from Bedi[9] were the basis for calculation of the reduction in expenditures and angler-days in sensitive areas due to exported power.

An amenity value was calculated based on travel costs for loss of participation in sensitive areas. The amenity value represents about half the total social cost value. It does not represent lost expenditure from Ontario, only a shift of expenditure from an acid sensitive lake area to a non-sensitive area within a 50 km distance. Appendix 2 outlines the calculations and Table 4 summarizes the results.

Table 4

Range of Sport Fishing Social Costs

(Cents/KW h of fossil exports 1986$)

Region	Year 1986
Algonquin	0-0.003
Northeastern	0-0.01
Total Range	0-0.013
Most Likely Value	0.007

Terrestrial Ecosystems - Literature Review

The terrestrial report[10] reviewed the effects of SO_2, NO_x, O_3, trace metals and acid precipitation on crops, forest production, vegetation and animals. Air pollution effects on crop yields have not been adequately quantified although they would vary (positively or negatively) according to species, pollution type and concentration and duration of exposure. Experimentally derived dose-response relationships have been estimated for mainly O_3 and SO_2. TGSs do not emit ozone but may influence its concentration through atmospheric chemical processes.[11]

Although some tree species are sensitive to SO_2 and O_3 under controlled experiments, to date ambient SO_2 and O_3 concentrations in Canada have not been demonstrated to cause reduced forest productivity. Laboratory and controlled field experiments using simulated acid rain have produced positive and negative results. The nitrogen and sulphur, which are essential elements for tree growth, have a fertilizing effect and can stimulate growth of tree seedlings used in experiments.

Tree growth decline and die-back observed in West Germany and the Northeastern US may involve a complexity of causes, more than just acid deposition, such as drought, SO_2, O_3, insects, pests and trace metals.

The indirect effects of air pollutants on animals through habitat modification (reduction in food, loss of habitat, etc) are probably greater than direct effects (trace element ingestion, reproductive problems, etc). Field studies conducted to date indicate that animals may avoid areas of higher pollutants or adapt genetically.

Terrestrial Ecosystems - Social Costs

No social costs for the effects of air pollutants from fossil-fired stations can be calculated for reductions in crop yields or forest productivity. However, although dose-response relationships and estimates of the value of crop loss due to O_3 have been reported, a determination of Ontario Hydro's export emission contribution to O_3 production in sensitive receptor areas is required before any social cost values can be calculated.

For animals, the methodology from the above mentioned aquatic report[7] was broadened to determine the social cost on aquatic based wildlife (waterfowl, otters and muskrats) (Table 5, Appendix 3). The loss of the aquatic food base through lake

acidification would result in a reduction in hunting and trapping activities (recreation days). Only participation of resident hunters in the affected regions of Ontario were used to calculate an amenity value and its subsequent loss with reduced waterfowl hunting opportunities.

Table 5

Range of Hunting and Trapping Social Cost

[Cents/kW.h of fossil exports (1986$)]

Region	Year 1986
Algonquin	0-0.001
Northeastern	0
Total Range	0-0.001
Most Likely Value	0

Structural Materials - Literature Review

Damage to economically significant structural materials (ie, concrete, metals, building stone, paints, textiles and glass), from SO_2, NO_x, particulate matter and acid rain was reviewed.[12]

The susceptibility of a material to damage is related to:

- Reactivity of the material to acidity.

- Moisture, acid gases and/or particulates on material surface, (exposure is a function of location and ambient pollution levels).

- Physical forces resulting from the volume changes associated with changes in the chemical composition of the material.

Damage to structural materials including historical property can be in the form of corrosion of metals, decay of building stone, erosion and colouration of paints and the weakening and fading of textiles. All of these effects occur to a significant degree as a result of, or in association with, natural environmental conditions, eg, moisture, O_2, CO_2, sunlight, particulate matter, etc. Quantification of the specific contribution of each factor, nature or anthropogenic, to materials' deterioration is difficult.

Structural Materials - Social Costs

The method of calculation of the social costs of fossil-fired emissions on structural materials was based on the Acres (1980)[13] and Salmon (1970)[14] methods with some modifications derived from the MOE (1984).[15] (Appendix 4).

Damage to the following structural materials was estimated: concrete, zinc, copper, aluminum, nickel, tin, paint, brick, stone and glass. Only damage costs due to dry deposition of SO_2 and wet deposition of SO_2 + SO_4 within Ontario were considered (Table 6). Soiling costs and a value of damage to cultural/historic property were not estimated because of a lack of reliable information. In the Acres (1980) report[13] the soiling costs for Lakeview, Lambton and Nanticoke TGS amounted to about 5% of the total soiling and deterioration costs combined (no estimate for cultural property effects was given).

Table 6

Range of Structural Material Social Costs

[Cents/kW.h of fossil exports (1986$)]

Region/Station	Year 1986
Northern Ontario	0
Southern Ontario	0.001-0.004
Lakeview	0.001-0.002
Nanticoke	0
Lambton	0.001-0.002
Total Range	0.003-0.008
Most Likely Value	0.005

Property Values - Literature Review

The results of 18 empirical urban studies were compared.[16] While almost all found a significant effect on property values, all were conducted under conditions of high pollution of the 1960's and 1970's mainly in US cities. The applicability of the results to the significantly low population levels in urban Ontario 20 years later is questionable.

Given the generally low pollution levels, the lack of variation in air quality within cities and the marginal contribution due to Ontario Hydro exports, air pollution due to exports is unlikely to be perceived by urban homeowners. Therefore, there is no likely social cost estimate for Ontario urban property.

Potential approaches to measure the effect of acid precipitation on rural property values were compared and evaluated. The market or implicit price model was found to be most applicable. The proposed model was described for potential application to recreational properties possibly in the Muskoka-Haliburton area. Data requirements, sources and availability were reviewed. It was concluded however, that because of the high cost and lack of apparent effects at the present time, it would be premature to conduct the empirical research.

3.0 REVENUE FROM ENVIRONMENTAL POLLUTION CONTROLS

As a result of Ontario Hydro's operations a number of by-products are formed. Attempts are made to recover revenue from them instead of directly discharging them to the environment. Since 1980 revenue has been generated from the sale of ash from fossil-fired stations, cobalt 60 from nuclear stations, timber from right-of-ways and waste oils from many locations throughout the Corporation. Future markets are being pursued for the sale of tritium, deuterium and heat energy.

Ash

Ontario Hydro successfully markets coal ash from TGS. In doing so not only is revenue generated but expenditures are saved on disposal costs. Over the last several years ash sales have been expanded into cement manufacturing processes and concrete applications and more recently into the clay brick, and, as stabilizing material for waste treatment industries. The historic use of ash in land reclamation projects and as structural fills in highway development has been maintained.

The past 5 years sales of these materials is shown in Table 7.

Table 7

Revenue and Disposal Savings of Coal Ash from TGS 1981-1985

Item	1981	1982	1983	1984	1985
Coal Ash Quantity (Mg)	157 870	99 000	138 648	190 440	211 178
Value of Sales ($)	146,990	67,742	126,687	207,878	296,295
Disposal Savings ($)	441,098	169,360	309,596	391,186	476,693
Total Benefits ($)	588,088	237,102	436,283	599,064	772,988

Timber

In the initial clearing of right-of-ways the original land owner has the right to purchase the timber cut at Hydro's cost. If he relinquishes this option, Hydro then calls for public tenders. In most cases Hydro only recovers its costs and therefore no revenue is generated.

Isotope Sales

For many years, Hydro has been selling isotopes unique to the CANDU nuclear system around the world.

Cobalt 60 remains the most important isotope. Under arrangement with Atomic Energy of Canada Limited (AECL) Hydro produces about 85 percent of the world's supply for marketing by AECL (Table 10). It is used in cancer therapy, for sterilizing hospital supplies and for the preservation of food. Over the last five years revenue in the order of 5 M$ to 10 M$ per year has been generated.

In the coming years markets are expected for deuterium gas (fibre optics), deuterated lubricants (long-life oils), and tritium (runway markers for remote airstrips).

Table 8

Quantities of Cobalt 60 Sold
from Nuclear Stations 1981-1985

Item	1981	1982	1983	1984	1985
Cobalt 60 Quantities (Mg)	12.36	13.07	11.3	8.63	21.33

Waste Oil

In Southern Ontario waste oil is shipped to Ontario Hydro's Kipling St. Complex where it is stored in a tank form for bulk sales to reprocessors. In Northern Ontario batch holdings of waste oils are sold to local reprocessors from individual Hydro sites (Table 9).

Table 9

Sales of Waste Oils
from Hydro Facilities

Item	1981	1982	1983	1984	1985
Reclaimed Oil Sales (Gallons)	70 000	70 000	70 000	70 000	70 000
Value of Sales ($)	100,000	110,000	110,000	95,000	70,000

Heat Energy

Hydro is developing markets for the sale of steam and hot water to industries in close proximity to generating stations. This steam will be 65 percent cheaper than steam generated by conventional sources.

The largest of these developments is the Bruce Energy Centre adjacent to the Bruce Nuclear Power Development. It will be ready for occupancy by the fall of 1986. Chemical, food processing, fibre board, plastic molding companies and greenhouse manufacturers are the main industries interested in waste heat.

Ontario's first commercial fish farm, Coolwater Farms, will utilize warm water discharge from Pickering Nuclear Station in 1986 to accelerate the growth rate of perch and trout fingerlings.

4.0 SUMMARY

Ontario Hydro recovers social costs from its electrical exports and revenue from by-products of its operations, thus reducing the total cost of energy production to its customers.

Social Costs

Export sales to the United States have benefited Ontario residents over the years by reducing annual rate increases up to seven percent. These export sales which equate to about five percent of our total annual production can have a community and environmental impact. The five social cost studies reviewed the effects of fossil-fired emissions (mainly SO_4, SO_2, NO_x, particulates, trace elements and acid precursors) generated as a result of US exports, on sensitive receptor areas - human health, aquatic and terrestrial ecosystems, structural materials and property values.

There is no direct evidence of long-term epidemiological effects on people attributable to these emissions for exports from Hydro's largest fossil-fired stations Lakeview, Nanticoke and Lambton TGS. However, these emissions can contribute to long-range transport and ultimately contribute to lake acidification in sensitive areas. This in turn can lead to changes in lake community structures.

Air pollution effects on crops and timber yields have not been adequately quantified to be of valid concern. Effects that have been observed cannot be directly related to fossil-fired emissions (ie, ozone effect on crops, biophysical effects on forests).

Lake acidification can have an indirect effect on the aquatic food base for waterfowl and furbearers.

Structural materials are susceptible to damage from dry and wet deposition. Susceptibility is related to material reactivity, moisture levels, surface exposure and pollutant concentrations.

In both urban and rural areas the effects of fossil-fired emissions/deposition on property values is not perceived as an issue. This includes the effects of lake acidification on recreational property.

The following is a summary of the social cost estimates, based on the five separate studies (Table 10).

Table 10

Summary of the Most Likely Values of Social Costs

[Cents/kW.h of fossil exports (1986$)]

Receptor	Year 1986
Human Health	0.031
Aquatic Ecosystem	0.007
Terrestrial Ecosystem	0
Structural Materials	0.005
Property Values	0
Total	0.043

These values should be considered as approximations, limited by the state-of-the-art of social cost methodology and by the estimates of emission/deposition levels.

The values quoted in Table 9 are approximately the same as the 1980 summary results (Table 2) taking into account the inflation rate between 1980 and 1985.

Revenue from By-Products

In addition electrical export social costs, Hydro also recover costs from many of its by-products such as ash sales, isotopes and waste oils. On an annual basis sales can generate revenue in the order of 5 M$ to 11 M$, mainly from the sale of Cobalt 60.

Table 1

1974 External Consultant Assessment of Environmental Effects and Social Costs of Electrical Exports

Receptor Area	Author	Environmental Effects	Social Costs cents/kilowatt-hour (1986$)
Health	Dr. T. Hamilton* Ontario Hydro(17)	1. Concentration levels in Southern Ontario are at or below the threshold for any measurable causation for: (a) decrease in ventilatory function and increase in respiratory tract infection in children. (b) increase in acute respiratory illness in families. (c) increase in adult chronic bronchitis. 2. Air stagnation during cold weather can aggravate asthmatic reactions in children, elderly and emphasematous.	0-0.14
Building Materials	Acres Consulting(18) Service	1. Some deterioration of material. In descending order of costs: Zinc, Paint, Copper, Nickel, Concrete, Aluminum, Brick, Tin, Stone and Glass. 2. Additional soiling of homes.	0.007-0.17
Textile Products	Ontario Research Foundation (19)	1. No deterioration of textiles. 2. Some soiling by particulates.	0
Great Lakes Water Quality	Acres Consulting Service (20)	Due to the strong buffering capacity of the Great Lakes, SO_2 has no effect on pH, water quality or toxicity.	0

*No external consultant could be found to complete study.

Receptor Area	Author	Environmental Effects	Social Costs cents/kilowatt-hour (1986$)
Vegetation and Animals	F.F. Slaney (21)	No damage to vegetation or health of animals.	0
Property Value	Peat Marwick (22) and Partners	No relationship between air pollution levels and property values in Metropolitan Toronto.	0
		Range	0-0.31

Table 2

1980 External Consultant Assessment of Environmental Effects and Social Costs of Electrical Exports

Receptor Area	Author	Environmental Effects	Social Costs cents/kilowatt-hour (1986$)
Health	Queen's University(23)	1. Normal low ambient pollutant concentrations aggravated with such harmful activities as cigarette smoking makes it impossible to accurately assess chronic exposure effects. 2. Oxides of sulphur and particulates are still the important pollution constituents mainly in children and adults with pre-existing chronic respiratory or cardiac diseases.	0-0.04
Building Materials	Acres Consulting Services(13)	1. Same ten materials as in 1974 were assessed (Table 1) Zinc, paint and concrete accounted for 80% of the total deterioration costs. 2. Acid precipitation can promote corrosion but can also wash away pollutants.	0-0.007
Textile Products	Ontario Research Foundation(24)	Fabric soiling by particulates still the only effect.	0
Water Quality*	Acres Consulting Services(25)	1. Hydro contributes to the loadings of sulphates and nitrates in the Haliburton-Muskoka area (2% - 4%) 2. Hydro emissions would take 23 years to seriously affect sport fishing instead of 24 years without Hydro emission.	0-0.006

*Mainly inland waters

Receptor Area	Author	Environmental Effects	Social Costs cents/kilowatt-hour (1986$)
Vegetation and Animals	Acres Consulting Service(26)	1. No measurable or visual damage to forests due to acid precipitation. 2. Trace element emissions are 1 to 3 order of magnitude lower than ambient criteria and have no toxic effects on animals.	0
Property Values	Peat Marwick and Partners(27)	1. Decline in pollution levels between 1968 and 1978 did not effect urban property prices. 2. No known effects of acid precipitation on recreational or non-urban property.	
		Range	0-0.05

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Appendices

Appendix 1

Format for Calculating the Social Costs of Health Effects

The estimate of social costs for Ontario due to fossil-fired electrical exports is calculated by:

(1) Ontario Health Costs:

total Ontario medical costs (direct and indirect) as a percentage of Ontario GPP x Ontario GPP ($).

(2) Contribution of exports to ground level concentrations (GLC): emission contribution to GLC x portion of overall energy exported (%).

(3) Percent increase in mortality/morbidity due to increase in pollution:

(2) x elasticity*.

(4) Total health costs due to exports:

(3) x (1).

(5) Health costs per kilowatt hours:

(4) x kilowatt hours.

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*Elasticity - unit free number that represents the expected percent change in mortality or morbidity rates associated with a doubling of the mean pollution value.

Appendix 2

Format for Calculating the Social Costs on the Aquatic Ecosystem

The estimate of social costs for Ontario due to fossil-fired electrical exports is calculated using the following formulas:

1. Rate at which lakes acidify due to atmosphere inputs:

$$Ta_1 = \frac{Alk \times Dm}{Ldh_1} \qquad Ta_2 = \frac{Alk \times Dm}{Ldh_2}$$

where Ta_1 = time to acidify with exports

Ta_2 = time to acidify without exports

Alk = total alkalinity of lake water (mg/m^3)

Dm = mean depth (meters)[a]

Ldh = hydrogen ion loading rate ($mg/m^2/yr$)
(h_1, h_2 as above a_1, a_2)
(total deposition rate - 50 $meq/m^2/yr$[b])

2. Percent of lakes sensitive to acidification:[8]
(200 mg/m^3 was assumed to be the upper alkalinity limit, below which lakes would acidify.)

Algonquin	72%
Northeastern	59%
Northcentral	40%

3. Losses in sport fishing participation or expenditures[9] due to exports:

$$[\tfrac{1}{2} E \text{ (or P)} \times K \times t_2] - [\tfrac{1}{2} E \text{ (or P)} \times K \times t_1] \text{ (Shaded area in Figure 1)}$$

where E = total annual expenditures (half the total annual expenditures for those partially fishing[c] ($)

P = participation in angler days ($)
K = proportion of lakes susceptible to acidification (%)
t_2 = time to acidify without electrical exports (years)
t_1 = time to acidify with electrical exports (years)

4. The above (3) is divided by the total exports in that year to give a loss per kilowatt hours.

5. An amenity value was calculated based on travel costs for loss of participation in sensitive areas.

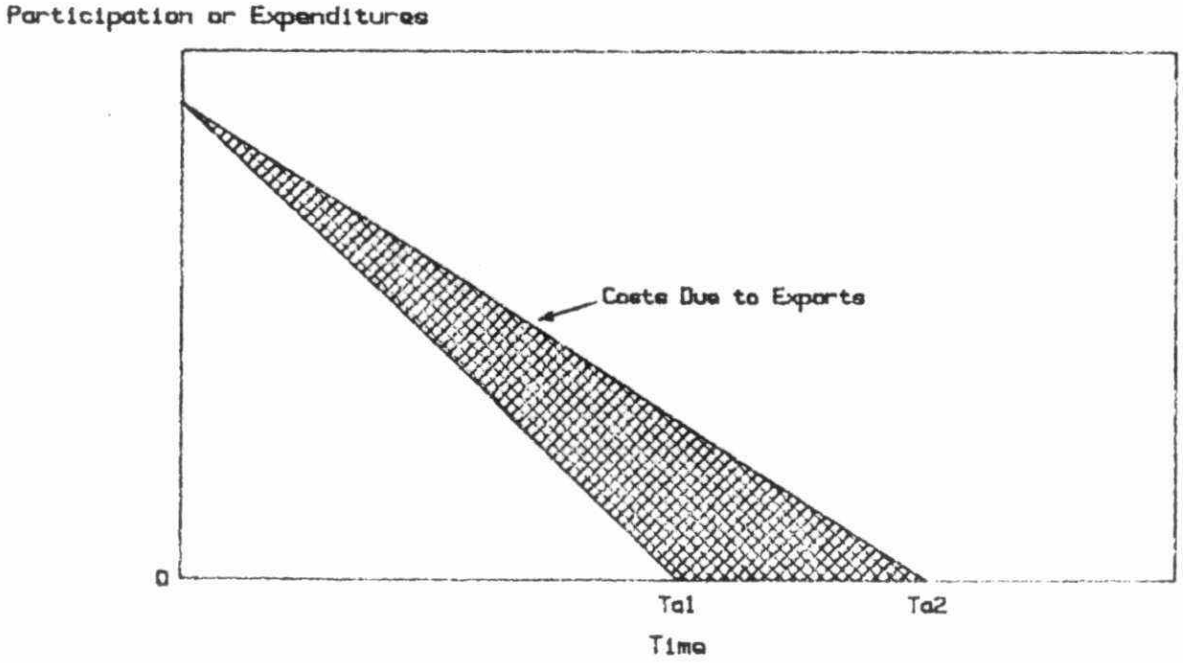
   (a) Minns (1981)[28] estimate the mean depth for 6,205 Ontario lakes is 6.1 meters.

   (b) Dillon et al (1984)[29] suggests that acidification occurs in lakes where deposition is 50 mg/m^2 of strong acid per year or more.

   (c) Expenditures were classed into four categories:

      (i) Ontario residents solely for sport fishing
      (ii) Ontario residents partially for sport fishing
      (iii) Non-residents solely for sport fishing
      (iv) Non-residents partially for sport fishing

FIGURE 1
Representation of the Derivation
of Losses Due to Electrical Exports



Ta1 - Time to Acidify with Exports
Ta2 - Time to Acidify without Exports

Appendix 3

Format for Calculating the Social Costs on the Terrestrial Ecosystem

The estimate of social costs for Ontario due to fossil-fired electrical exports is calculated as follows:

1. Fishing losses through lake acidification, (Appendix 2) is broadened, to the further implications for hunted piscivorous (fish-eating) waterfowl, other waterfowl, otters and muskrats,

$$(\frac{1}{2} E \text{ (or P)} \times K \times t_2) - (\frac{1}{2} E \text{ (or P)} \times K \times t_1)$$

where E = total annual expenditures on waterfowl hunting ($)

P = participation in waterfowl hunter-days ($)

K = proportion of lakes susceptible to acidification (%)

t_2 = time of acidify without electrical exports (years)

t_1 = time to acidify with electrical exports (years)

2. The above (1) is divided by the total exports in that year to give a loss per kilowatt hour.

3. Use formula in (1) and recalculate and add to formula (1) the revenue lost for furbares pelts by substituting revenues from pelts for waterfowl hunting expenditures.

4. An amenity value was calculated based on travel costs for loss of participation in sensitive areas.

Appendix 4

Format for Calculating the Social Cost on Building Materials

The estimate of social costs for Ontario due to electrical exports of fossil-fired emissions is:

$$E = \frac{(\sum D_r + S + H)}{P}$$

where E = estimate of social costs per kilowatt hour due to export of electricity;

$\sum D_r$ = total value of materials damage in region r (eg, sum of value of damage to zinc, concrete, etc, due to corrosion, erosion, etc);

S = soiling costs;

H = value of damage to cultural properties;

P = number of kilowatts of electricity produced by fossil-fired generating stations for export.

The value of material damage is estimated by:

$$D_r = C \times L \times V \times E \times I_r \times P_r$$

where D_r = annual economic value of damage to a specific material in region r;

C = annual consumption volume of materials in Ontario;

L = average economic life of the material;

V = value added or labour factor;

E = exposure factor;

I_r = interaction value in region r;

P_r = population factor for region r.

QUEBEC'S EXPERIENCE WITH THE ECONOMIC EVALUATION OF ENVIRONMENTAL REGULATIONS: WHAT LESSONS HAVE BEEN LEARNED

Paper presented at the Environmental economics session of
the Technology Transfer Conference
Toronto, December 8, 1986

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INTRODUCTION

As in other governmental instances, the Government of Quebec introduced, in June of 1981, the requirement to evaluate the economic implications of new regulations that may have an effect on industry. This requirement applies in particular to legislation of a social character and especially to environmental regulations.

The adoption of that measure was made in a general context of deregulation - should we call it the first step of the present deregulation wave - that concentrated on the burden that government regulations impose on the private sector. Governments across North America where becoming more and more conscious that their importance in the economy had grown considerably on the preceding decades and that the costs tied to their different interventions particularly regulations, were bearing more and more heavely on their economic system.

Here in Canada, let us recall that following the First Ministers meeting of February 1978, the Economic Council of Canada had been requested to "undertake a number of studies of specific areas of government regulation which appear to be having a particularly substantial economic impact on the Canadian economy".

Under that "regulation mandate" the Council produced a number of position papers and studies in the following two years which still fuels the deregulation debate. Meanwhile the Federal government had taken the lead by initiating its own Socio-Economic Impact Analysis (S.E.I.A.) by August 1978.

Under the E.C.C. mandate, environmental regulation was clearly identified as one of the areas perceived to impose substantial negative impacts on the economy. Since the mid 1960's, regulatory activity

was particularly intense in the environmental sector. As an illustration, let us only consider that there were at least eleven studies on environmental regulations that were commissionned by the Council under its mandate.

In the U.S. it was at the beginning of (1981) that President Ronald Reagan issued a new Executive Order that emphasized the importance a measuring the costs and benefits of federal regulations, stressed the significance of the resulting analysis and put the Office of the Management of the Budget (O.M.B.) in a central role to ensure compliance with the cost/benefit procedures. That Executive Order replaced the Carter administration's own regulatory analysis review program initiated in 1978.

More recently, the debat has widened to the general theme of government intervention in the economy and has become, in Quebec, one of the central theme of governmental policy.

The publication, at the beginning of this summer, of a series of reports on government organization, deregulation and privatization by work-groups appointed by the Quebec government and the privatization of a number of Crown owned enterprises mark clearly the will of the present government not only to engage in an active deregulatory process but also to lessen the importance of government related activity in the economy.

We can immediatly establish a parallel with the Nielson report to the Federal government and realize that the context is evolving in a somewhat systematic fashion.

The Quebec economic evaluation of new regulations procedure

The economic evaluation procedure was introduced by Cabinet decision on June 1981. It required that all proposed regulations submitted to Cabinet be accompanied with a summary of an impact study done by the proposing Ministry. The study summary should be along the general outlines described in table 1.

The procedure was designed to be applicable to all forms of new regulations including modifications to existing regulations.

From an administrative standpoint, in addition to the standard rulemaking and Cabinet approval process, a proposed regulation with its accompanying impact study had to undergo the scrutiny of the Permanent Ministerial Comittee on Economic Development which generally coordinates Ministries actions and advise government on economic development matters.

In fact, the new procedure introduced a new actor in the negociation process that a regulation has to go through before going for Cabinet approval.

TABLE 1

Outline of an Economic evaluation study

A) Description of the problem and major objectives:

1. Advantages and disadvantages of the present situation.

2. Comparison with the situation elsewhere.

B) Possible action scenarios.

C) Description of the options considered.

D) Economic evaluation of the options

1. Benefits
   -User's benefits
   -Benefits accruing to industry

2. Costs
   -Investment costs
   -Production costs
   -Transaction costs
   -Indirect costs

E) Governmental impacts

-Budgetary impacts
-Fiscal impacts
-Coherence with other governmental actions

It should be stressed, as this point, that we have not yet used the term Cost/Benefit Analysis (C.B.A.) to describe the economic evaluation process. Looking at the general outline in table 1, you don't find any explicit reference to it. Not that it is excluded as such, but the general philosophy behind the evaluation is more in terms of introducing an economic rationality in the designing of regulations than the systematic application of a technique.

Another thing we want to stress, and that doesn't comme out clearly in table 1, is the importance given to the formulation of alternatives to regulations in the evaluation process. The basic idea was to introduce at the base of the regulatory process the consideration of complementary or alternative modes of intervention and to evaluate them comparatively to the regulatory approach.

Finally, even if the focus was on economic evaluation, the framework of the impact study was designed to cover systematically the rationale, the formulation of specific objectives and government impacts. These aspects were already covered in the standard "memoires" to Cabinet but not in a technical fashion. In effect "memoires" can be conceived as negociation documents in the regulatory process compared to economic evaluation studies which are more technical in nature.

The economic evaluation process at the Quebec Ministry of Environment

Like all other Environmental Agencies, the Quebec Ministry of Environment relies mainly on regulations to promote its objectives of environmental quality.

"Regulation production" is therefore an important continuing activity at the Ministry. The economic evaluation procedure was then perceived as a threat to those activities, and surely an additional obstacle in the already difficult rule-adoption process.

In addition, putting dollar figures on the environment didn't quite fit the environmental culture inherited from the earlier decades. Consequently, it wont surprize anyone to say that the introduction of the economic evaluation procedure was a difficult process.

Most of the ministries major pieces of regulations having been adopted in the second half of the seventees, the economic evaluation procedure applied essentially to modifications of these. To give a better perspective of the environmental regulation universe in Quebec, let us consider that there are essentially eleven (11) regulations which have a major environmental thrust.

Since 1981, one new regulation was introduced (drinking water) and there has been amendments to at least five existing regulations. Each of these went through the economic evaluation process. We have to add to that, a number of amendments on the majority of the remaining regulations which are still in the Ministries pipeline uncluding a new regulation on pesticides. For all of those, the economic evaluation procedure is applied.

Considered at the beginning as an impedement to the Ministries regulatory action, the evaluations were made at the end of the line of the internal rulemaking process. Collaboration with those responsible for the elaboration of the regulations was difficult: The new procedure

was considered, in fact, a loss of power by the rulemakers. Someone had changed the rules of the game. The traditional conflict between economic and environmental values had to be faced and resolved.

Since then, the situation has evolved and the economists responsables for those evaluations are progressively involved in the rule making process. A new dynamic has been created and the results to date indicate we are progressively going from a symbolic approach to a more pragmatic approach in regulatory action.

For those who are not familiar with the symbolic nature of environmental regulations, reference should be made to the numerous studies on environmental regulations made under the E.C.C. regulation mandate and the recent studies commissionned by the Law reform Commission of Canada.

Suffice it to quote, from the Thompson Study made under the regulation mandate

> "... bargainning is the essence of the environmental regulatory process as it is practiced in Canada... the reality is that the rules of environmental regulation are never clearly stated or certain, except in a purely symbolic sinse."[1]

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1 Andew R. Thompson, "Environmental regulation in Canada: An Assessment of the Regulatory Process". A study prepared for the Economic Council of Canada by the Westwater Research Center U.B.C., 1980.

Problems and lessons

In doing those economic studies we have encountered a number of problems and learned quite a few lessons.

One of the basic problems we've encountered is the lack of environmental data.

Here, the problem can be broken down into two components. First, the lack of a specific scientific database and expertise creates a situation where in many fields of environmental activity the Ministry has to rely on international or federal data and expertise complemented with factual information. Second, the scientific database is not adapted to provide the kind of input necessary for precise benefit description. Neddless to say that dose-response relationships are a rare species.

That kind of situation undermines continually the process of benefit qualification and evaluation and particularly the definition of specific objectives.

In addition, the formulation of alternative options which the evaluation procedure was suppose to generate did'nt work very well. The general scenario was essentially to present two options: the "status quo" and the solution proposed which was, evidently, an amended regulation or a new one. The evaluation study became rapidly a strategic document for the Ministry and the exercice did'nt produce the results expected, at least in the beginning.

The focus, as far as economic evaluation is concerned, was therefore on costs: Investment costs, operation and maintenance costs, paperwork costs.

The case is classical amongst environmental agencies engaged in economic evaluation of their regulation. The process even implicity questioned the scientific foundation of the regulations because of the lack of scientific data.

At a certain point, the economic evaluation study was even perceived as a way of giving the Ministries promoting economic development, supplementary arguments to kill the proposed regulation.

All this looks quite negative but on a second thought, the situation induced the questionning of the way we were looking at the evaluation and more importantly at regulations.

When we examine the Ministries internal rulemaking process, we find an iterative process in which the economic evaluation study now plays a vital role. In this type of process you can have quite a number of economic evaluation embedded in an evolutionnary formulation of a proposed regulation. In parallel to that we must consider the bargaining process which traditionnaly takes place between the Ministry and other affected government agencies or Ministries and Industry. This last issue has been deal with quite extensively in the litterature, namely Dewees.[2]

The focus being on costs, the first question asked became "Are the costs reasonnable" implying "Can we reasonnably presume that industry can bare those costs?" And we found ourselves doing detailed financial analysis to try to determine if the regulation could have a disruptive effect on industry.

The second question asked was "How does the proposed regulation compare with what you find elsewere particularly in economies were you find competing industries?"

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2 Donald N. Dewees, "Evaluation of policies for regulation environmental pollution", Economic Council of Canada by the Westwater Research Center U.B.C., 1980.

That kind of question focusses on what, in the proposed regulation, is different from what they're regulating elsewhere: What is the specific justification for being different?

At this point, it should be noted that this line of reasoning is a long way from comparing the benefits and the costs in the formal framework of Benefit/Cost analysis. The treatment of the costs in such a fashion resulted in considering, at first, technical alternatives to render the costs acceptable to industry whatever the word "acceptable" means without sacrificing any environmental objectives. As far as the benefits are concerned, they are valued for themselves and therefore they are essentially the object of the socio-political system. But the procedure introduced enormous pressures to define and express them in a more articulate manner.

The net effects of this process, in a context of severe budgetary restraint, is twofold. First, a widening of perspective in considering the tools available to reach environmental objectives. Second, increased efforts and resources devoted to the articulation of the benefits of the actions proposed.

The Ministry is in effet quite rapidly moving towards the consideration of complementary alternatives to the traditionnal regulatory approach. It also is engaged in a process of articulating its specific objectives and the benefits derived from its action. Essentially, the Ministry is reacting to its own way of putting the questions of the economic impact of its own regulations.

I would like to conclude, from this breef look at the practical experience of economic evaluation of environmental regulations in Quebec, that:

- The natural reference to the Cost/Benefit Analysis technique when we speak of the application of the economic rationale to environ-

mental problems, may be essentially a problem of terminology with a symbolic character.

The common sense base for the justification of the technique is sound. No one would want to question that. But we must remember that environmental problems still have a high socio-political content in our society. In that sense, benefits are not valued on the same basis as the costs. We just have to look at the acid rain problem to convince ourselves of that reality.

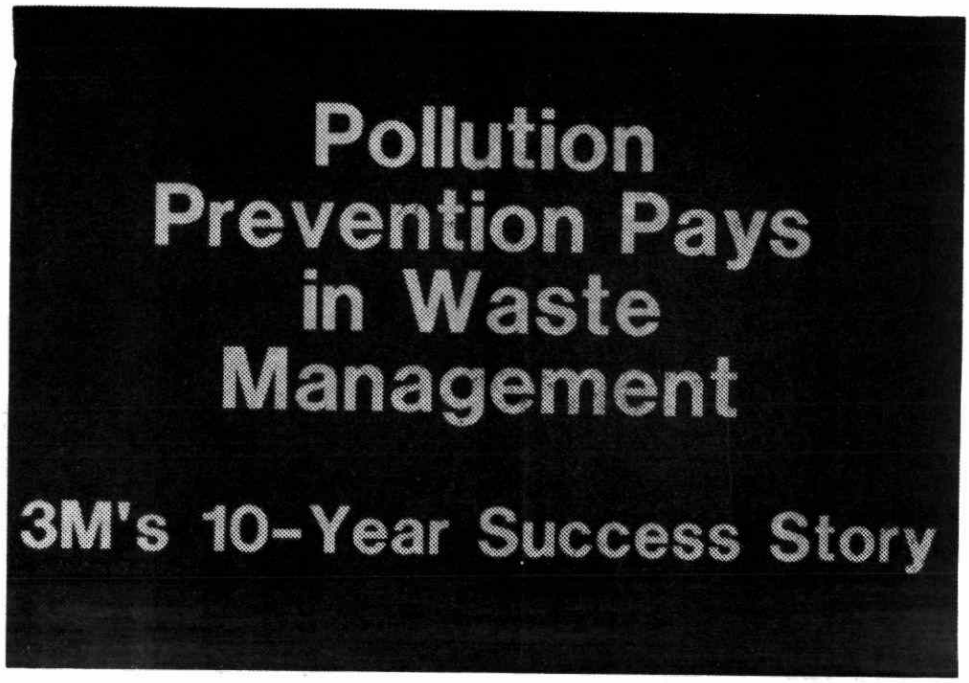
- When we analyse the pattern of change which has taken place at the Quebec Ministry of the environment since 1981, we find that the approach of introducing the economic rationale in the rulemaking process as opposed to the compulsory use of a specific technique like Cost/Benefit Analysis, has had an interesting effect: Scientists and engineers who are intimately involved in the environmental rulemaking process come to view economists and their way of looking at problems, as strategic allies in promoting their environmentals objectives. They are bringing in a new set of tools at a time when the regulatory tool is subject to very strong attacks. We should not confuse what we call "environmental economics" with the application of a technique.

- Looking a our modest experience at the Ministry and at the present worldwide interest in reconcyling economic with environmental principles, I think economists have a point to make: in the present economic context, they have a crucial contribution to make to environmental policy making and this contribution owns more to their attitude and imagination than to their technique.

3M'S POLLUTION PREVENTION PAYS PROGRAM
TECHNOLOGY TRANSFER CONFERENCE - DECEMBER 8, 1986
TORONTO, ONTARIO

Mr. A.G. Mills
Vice-President, Technology Services
3M Canada Inc.

It is indeed a pleasure to participate in this important conference and to describe a program within the 3M Company that has caused a change in the approach that we have taken to developing our products and managing our businesses.



SLIDE 1

We have had a good deal of publicity over our "Pollution Prevention Pays Program" in the eleven years of its existence. At the outset there was considerable debate as to whether the word "Pays" should be associated with environmental activity. But we identified four valid pay-offs including an improved environment; conserved resources; improved technologies; and reduced costs. Now with over a decade of experience with the Program, we can demonstrate that the Pollution Prevention Pays or that our "3P" concept really does work.

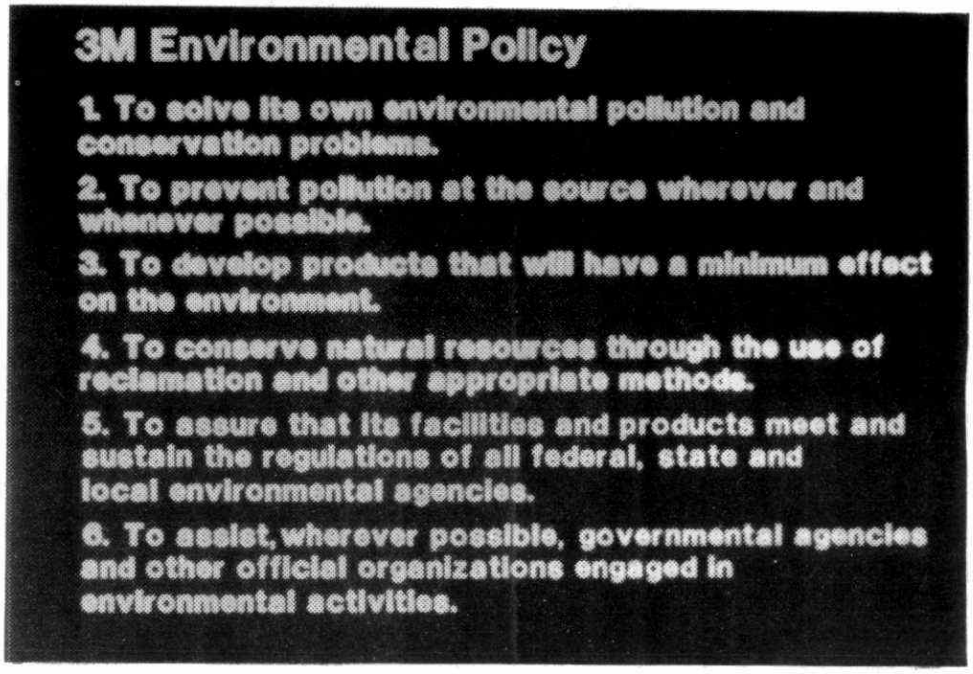
I would like to tell you how the concept evolved, give you some examples of successful projects, and indicate our progress towards "Institutionalizing" the Program and the notion that Pollution Prevention Pays. We feel we will truly be successful when our scientists, our engineers, and technicians keep this notion on their minds as they develop new products and processes.

As many of you may know, 3M is a large multinational corporation with a highly diverse product line.

In 1985, on a world-wide basis we had sales of nearly $8 billion. In Canada, our sales exceeded $400 million with a good portion of this in the form of export business.

As a company, we sell over 40,000 different products and we like to say that, each day close to half of the world's population benefits in some way from our 3M products. Around the globe, millions of people watch television recorded and broadcast on our "Scotch" Brand Video Tape; find their way with the help of "Scotchlite" Reflective Road Signs; take comfort from 3M Health Care and Safety products; smooth out the rough edges with 3M Sandpaper; or hold things together with 3M Adhesives and "Scotch" Brand Tapes.
As a company, we have established a reputation for innovation in the development of new products. In fact, as a corporate goal, we look for 25% of our sales in any one year to come from products that have been introduced in the last five years.

It is because we are a new products oriented company, where products and processes are constantly being invented or modified, that it has been somewhat easier for us to incorporate pollution prevention into our activities.
While that may be true, the fact that we have Manufacturing Plants in several locations in the U.S., in over 40 Countries around the world and in four locations in Canada, complicates compliance with Environmental Regulations.



SLIDE 2

Corporate Management recognized this back in 1975 and provided a set of guidelines to work by - our Environmental Policy Statement. Points 5 and 6 essentially say that we will comply and we will cooperate.

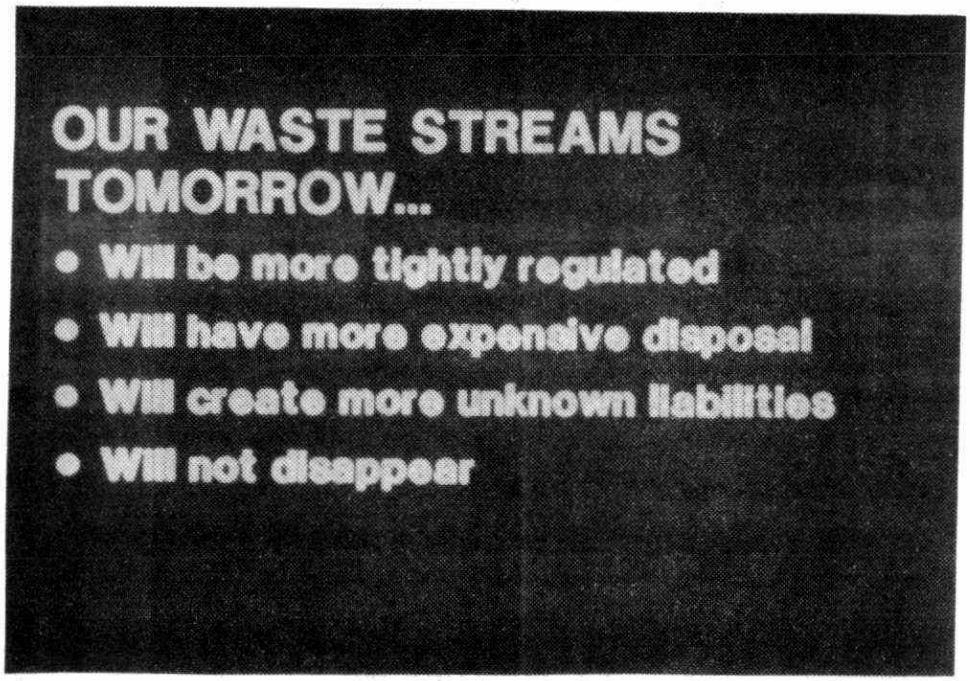
But points 1 through 4 go considerably beyond this and lay out a strategic approach of solving our own problems, conserving resources and reducing or preventing pollution at the source.

SLIDE 3

This policy carries over to our waste handling strategy. Here again, emphasis is on minimizing waste at the source.

But we also recognize that treatment of existing waste streams may be required by regulation, reduction of potential future liabilities or just good corporate citizenship.

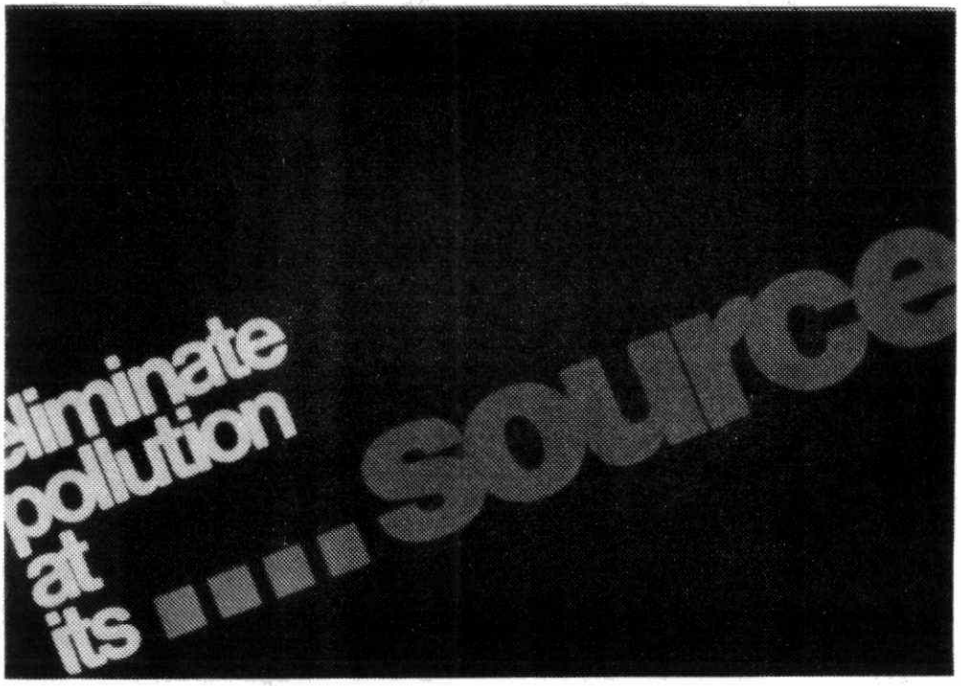
Our waste handling strategy obviously applies to all forms of pollution: air, water, and solids.



SLIDE 4

One thing is certain, our waste stream tomorrow will be:
- more tightly regulated;
- more expensive to dispose of;
- create more unknown liabilities;
- will not disappear.

A major part of our waste handling efforts involves minimizing waste. We reckon that without the effects of this program over the past eleven years, the amount of waste we generate today would be twice what it actually is.



SLIDE 5

The heart of the 3P program is in preventing pollution or waste at the source so that treatment at the end of the manufacturing process is not necessary.

Source prevention applies not only to the process for making a product, but also to the product itself. We want to make sure that after our product leaves our manufacturing locations, that it does not become a source of pollution for our customer down the road.

Attacking the problem at the source is not a new idea. It has been around for many years - but generally used on a piecemeal basis. The unique aspect of the 3M - 3P program is that it applies the pollution prevention concept on a comprehensive, company-wide basis around the world.

There are four basic ways to prevent pollution at the source:

SLIDE 9

1. Develop non-polluting products or reformulate existing products. This is simply done by substituting non-polluting materials for ingredients that are pollutants.

   A good example of this is our effort to substitute water-based adhesives for those that contain solvents. These solvents are pollutants because, untreated, they contribute to the formation of ozone in the atmosphere.

2. Modify production operations. For example, convert to a solventless coating process as we have in our Perth, Ontario location. Or change from a batch to a continuous process in order to reduce peak discharges.

3. Redesign equipment used in a manufacturing process. For example, at one of our plants, we converted a boiler so that it could burn solvent laden exhaust from a coater, thereby eliminating add on pollution control equipment, in addition to providing significant savings per year in energy costs.

4. Recover and recycle waste products. As an example, at one of our plants, a film developing unit generated waste water containing 1,1,1-trichloroethane.

   A Decanter System was installed to recover the developer for later distillation and recycling. The Decanter System cost $4,000 but produced cost savings of over $20,000 over the first four years of operation.

3M has many examples of successful projects in all four basic categories - with cost savings ranging from a few thousand to hundreds of thousands of dollars.

Our most prolific categories have been reformulation and recycling. But we recognize that for other companies, their best opportunities may lay in a different set of categories. It is clear however that the four categories are the same, regardless of products or processes.

SLIDE 10

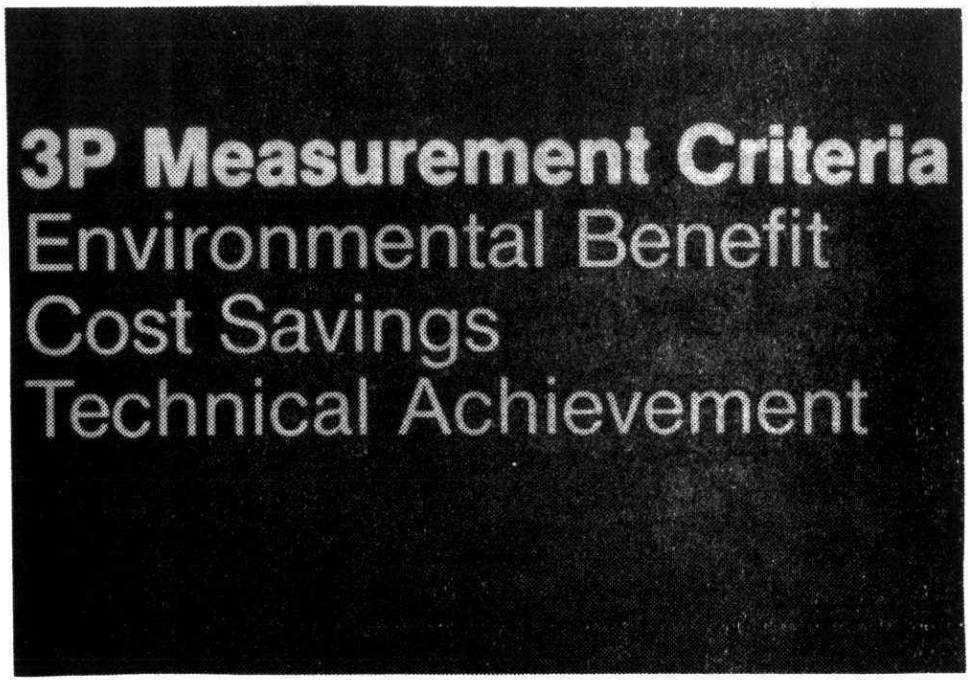
And now for a look at how the 3P program works.

Above all, it is a corporate-wide program fully endorsed by management at all levels. Our Chief Executive Officer is one of its biggest supporters. All of our operating divisions and our subsidiary operations are encouraged to participate.

It is mainly directed at the company's technical employees in Manufacturing, Engineering and our Laboratories. They are responsible for our products and processes and thus the ones most able to work on pollution prevention at its source.

Working in their own specialty areas, doing the work they know best, they are asked to implement pollution prevention concepts in their everyday activities.

When they believe they have made a worthwhile accomplishment, they submit their effort to a 3P Coordinating Committee of Laboratory, Engineering and Manufacturing representatives for review.



SLIDE 11

Each submission is judged on the following criteria:

1. It must result in an environmental benefit that can be quantified, such as the amount of pollution prevented.
2. It must produce a cost savings for the company.
3. It must demonstrate a technical achievement or an innovative approach above and beyond standard engineering or manufacturing procedures.

If the idea meets with peer approval, then and only then is it accepted as a 3P project.

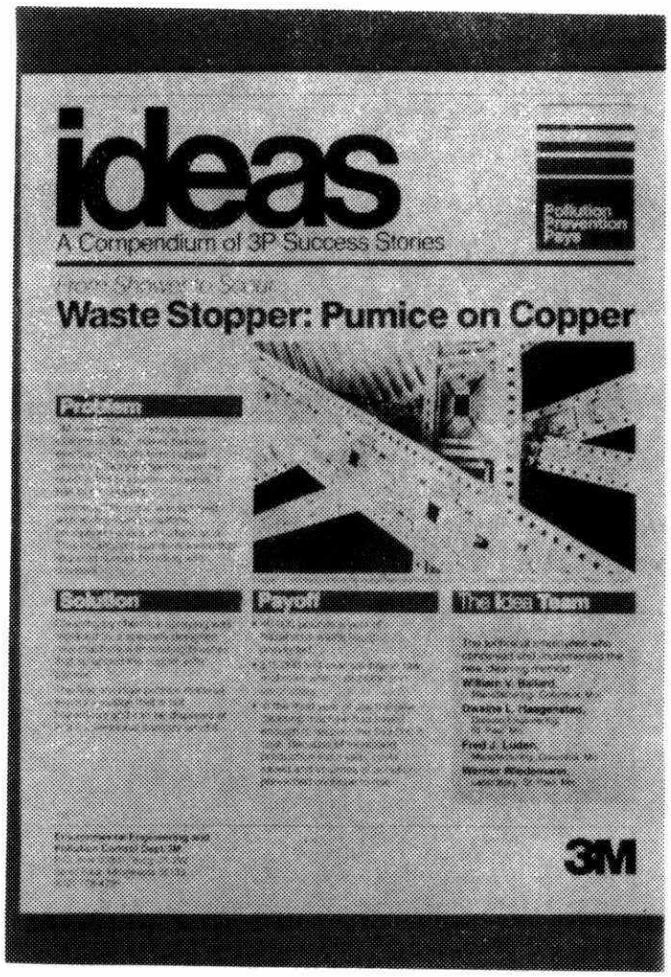
Contributors to the program have proven to be among 3M's most creative technical employees and this recognition serves to reinforce their reputations and contribute to their career growth. Recognition is the only immediate award and we avoid prizes or cash awards that smack of contests or promotions.

Because of strong management support, our annual management review take note of which divisions are doing the most, and the least, to produce 3P projects.

The net result is that the Program continues to grow and the results get better each year.

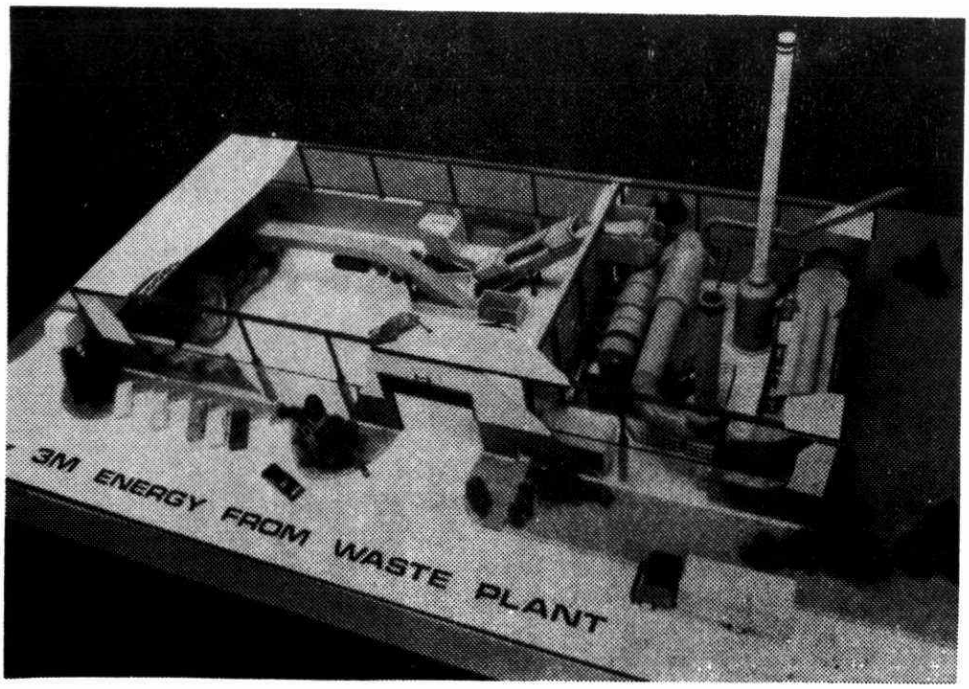
A significant part of the 3P Program involves communication, both inside and outside the company.

Internal communications have concentrated on sharing 3P success stories with others in 3M around the world. These one-pagers combine technical, economic and environmental information in an easy-to-read form with a little humour thrown into the headline.



SLIDE 12

This one, "From Shower to Scour Waste Stopper: Pumice on Copper" - describes a project in which copper circuits are now cleaned by scrubbing with pumice rather than by spraying with corrosive acids. The result is non-hazardous waste instead of 40 pounds per year of hazardous waste, and a fast 2-1/2 year payback on investment.



SLIDE 13

Another example involves a project initiated at our 3M Canada Headquarters in London, Ontario. This project, an Energy from Waste installation, has attracted a good deal of publicity in the area, and is an excellent example of how serious environmental problems can be reduced within the community.

The genesis of the project came while considering how to control a Tape Oven Exhaust that produced an odour under certain climatic conditions. At the same time we were very conscious of the amount of dry, non-hazardous waste we were sending each day to the municipal landfill site.

The solution---an Energy from Waste Plant that will use our tape exhaust stream and dry waste material as fuel augmented by similar waste from surrounding Industry.

As a result we expect to eliminate the odour, reduce the number of trucks of waste on London streets and, of course, extend the life of the landfill site.

With this project we will not only control our waste but the heat generated by the incineration process will make us largely self-sufficient in the generation of steam for our manufacturing operations.

The 3P mentality and the solid support the concept has within the company eased the acceptance of the project at 3M even in the face of some community concerns.

While not related to our project in any way, a PCB problem within the immediate area of our plant affected the outlook of our neighbours as did an earlier EFW proposal by a local hospital which created wide media and local interest and concern.

Again the 3P concept provided us with sensitivity to the needs and concerns of our employees and neighbours alike and allowed us to develop an information program that provided all interested parties with all the information they needed as to the scope and implications of the project.

In fact the very existence of our 3P Program was used as evidence in our submission to the Ministry of the Environment for approval of the incinerator

as an indication of the culture in place at 3M that motivated us to propose such a project.

Clearly we believe strongly in the 3P concept. And, we do not hesitate to "sell" the concept to others because we believe industry can establish a leadership position in the environmental area - a position that industry has shunned too often in the past.

The 3P concept has been adopted by many others - organizations, companies, and even the United Nations. The U.N. has been most interested in the 3P concept because it represented, in their estimation, the only affordable approach to environmental protection for the less developed countries.

Those factors that make the 3P approach valuable to industry in the developed countries of the world apply equally well to those countries who are still struggling with the basics of existence.

In summary, since the Program's inception in 1975, 3P projects have saved over a quarter of a billion dollars world-wide for 3M.

These costs reflect pollution control facilities that did not have to be built, reduced pollution control operating costs, reduced manufacturing costs, and retained sales of products that might have been taken off the market as environmentally unacceptable.

We expect these cost savings to continue to grow as more and more of our people begin to think of new ways to prevent pollution.

The Program world-wide has yielded equally good results from an environmental standpoint as from a monetary viewpoint.

Tons of air pollutants and water pollutants have been eliminated from the environment in the area of our manufacturing locations.

These 3P results are an illustration of what can be done. The encouraging word today is that many companies are in fact eliminating or reducing pollution at source.

They are demonstrating that there is, indeed, a payoff in managing for a better environment and in preventing pollution at its source.

SLIDE 14

THE BENEFITS OF REDUCING LEAD IN U.S. DRINKING WATER

R Levin, U.S.-EPA, Washington, D.C., U.S.A.

The Safe Drinking Water Act (SDWA), passed by the U.S. Congress in 1974, requires the U.S. Environmental Protection Agency (EPA) to protect public health by setting drinking water standards for public water supplies.* Two levels of protection are described in the SDWA. Primary drinking water regulations, applicable only to public water systems, specify contaminants that may have an adverse effect on human health and, for each contaminant, set either a maximum contaminant level (MCL) or a treatment technique requirement. Secondary drinking water standards are non-enforceable recommendations concerning the aesthetic quality of drinking water, e.g., taste or smell.

The National Primary Drinking Water Regulations (NPDWR) were first promulgated at the end of 1975. EPA revises those regulations by setting maximum contaminant level goals (MCLGs) and related MCLs. MCLGs are non-enforceable health-based goals, intended to protect against known or anticipated adverse health effects, with an adequate margin of safety. MCLs are enforceable limits, to be set as close as feasible to the MCLG; feasibility includes cost and technological constraints. MCLs are proposed at the same time as the MCLGs.

On November 13, 1985, EPA proposed National Primary Drinking Water Regulations (NPDWR) to set MCLGs for 24 synthetic organic chemicals, 10 inorganic chemicals, and 6 microbiological parameters

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* Defined in the Act as water systems serving 25 or more people or having at least 15 service connections.

in drinking water; these substances are listed in Table 1. The proposed MCLGs for probable human carcinogens were set at zero, and MCLGs for other substances were based upon chronic toxicity and other data.

Lead is included among the inorganic substances proposed for regulation in the NPDWR. The current MCL for lead is 50 micrograms of lead per liter of drinking water (ug/l);* the proposed MCLG is 20 ug/l.

Summary of Study

This analysis estimates some of the benefits that will result from the proposed reduction in the MCL for lead in community drinking water supplies. There are two primary categories of benefits in this paper: the public health benefits of reduced lead exposure and reduced materials damages relating to the phenomenon of lead's presence in drinking water -- as a corrosion by-product. In addition, because the calculation of health benefits depends on the extent of human exposure, another section presents the available data on the occurrence of lead in public water supplies, and presents estimates of the population exposed to drinking water exceeding the proposed MCL of 20 ug/l.

This analysis estimates the annual benefits for one sample year, 1988, of lowering the MCL from 50 ug/l to 20 ug/l. That one year was chosen because environmental lead levels will have

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* This is equivalent to and can be alternately stated as 0.05 milligrams per liter (mg/l), 0.05 micrograms/gram (ug/g), or 50 parts per billion (ppb).

TABLE 1. Substances Included in the 1985 Proposed National Primary Drinking Water Regulations (MCLGs)

A. Synthetic Organic Chemicals

1. Acrylamide
2. Alachlor
3. Aldicarb, Aldicarb sulfoxide and Aldicarb sulfone
4. Carbofuran
5. Chlordane
6. Dibromochloropropane
7. o-,m-Dichlorobenzene
8. cis- and trans-1,2 Dichloroethylenes
9. 1,2-Dichloropropane
10. 2,4-D
11. Epichlorohydrin
12. Ethylbenzene
13. Ethylene dibromide
14. Heptachlor and Heptachlor epoxide
15. Lindane
16. Methoxychlor
17. Monochlorobenzene
18. Polychlorinated biphenyls
19. Pentachlorophenol
20. Styrene
21. Toluene
22. Toxaphene
23. 2,4,5-TP
24. Xylene

B. Inorganic Chemicals

1. Arsenic
2. Asbestos
3. Barium
4. Cadmium
5. Chromium
6. Copper
7. Lead
8. Mercury
9. Nitrate and Nitrite
10. Selenium

C. Microbiological Parameters

1. Total Coliform Bacteria
2. Turbidity
3. Giardia
4. Pathogenic Viruses
5. Legionellae
6. Heterotrophic Bacteria
7. Treatment Technique Requirements
   a. Mandatory Filtration and Disinfection of Surface Water for Microorganisms
   b. Mandatory Disinfection of Ground Water

stabilized following EPA's 1984 phasedown of lead in gasoline.*

For comparability, all monetary values are expressed in 1985 dollars, using fixed-weighted price indexes for the gross national product (Table B-4), from the 1986 Economic Report of the President to Congress.

1. The Occurrence of Lead in Public Drinking Water

Lead occurs in drinking water primarily as a corrosion by-product; its sources are the materials used in the distribution and residential plumbing systems (cf sources as diverse as the EPA Air Quality Criteria Document for Lead, 1986; Craun and McCabe, 1975; Kuch and Wagner, 1983; Lead in (British) Drinking Water, 1977; etc). Pipes and solder containing lead are corroded by water, and lead levels at the user tap are much higher than those found at the treatment plant. While the presence of lead service pipes and mains is relatively restricted geographically in the U.S., the use of lead solder (and flux) is ubiquitous. And the combination of copper pipes with solder containing lead found in most households can result in high lead levels** -- levels exceeding the current MCL, even with fairly non-corrosive waters (e.g., Nielson, 1976). In particular, newly-installed solder is easily dissolved, and people living in new

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* Specifically, this analysis measures effects given the conditions on January 1, 1988, when EPA's proposed ban on leaded gasoline will not yet have taken effect. However, even if EPA promulgates the ban, the estimates in this report will not change significantly.

** This results from galvanic corrosion, which is the corrosion that occurs when 2 metals, with different electro-chemical potential, are in the same environment.

housing are especially at risk of high levels of lead in the drinking water (Sharrett et al., 1982; Murrell, 1985).

We used several sources of data to develop a national profile of exposure to lead from community drinking water supplies.* These included the 1978 (U.S.) Community Water System Survey, the (U.S.) National Inorganics and Radionuclides Survey (conducted by EPA), the (U.S.) Federal Reporting Data System (EPA's drinking water compliance data base), data from the WaterTest Corporation (a private water testing company), and data from the Culligan Company (a water softening firm) analyzed for EPA in 1979-81 by J. Patterson. Based upon the observations contained in these data sets, we estimate that at least 28.5 million people (lower bound: 20.8 million) currently receive water that has over 20 ug/l of lead.

To this must be added the inhabitants of housing built within the past 24 months. Many studies have shown that new solder can release significant amounts of lead into water, even exceeding the current MCL. While corrosive waters have the highest lead levels, relatively non-corrosive waters can also leach significant amounts of lead. The highest lead contamination levels occur with the newest solder (i.e., during the first 24 months after installation), but lead levels can remain elevated for five years (e.g., Sharrett et al., 1982; Lassovszky, 1984).

There were 1.7 million new housing starts and permits (public and private) in 1983 and 1.8 million in 1984.** Assuming that

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* The occurrence data we used relate to the approximately 60,000 community water systems that serve about 219 million people.

** Survey of Current Business, U.S. Department of Commerce - Bureau of Economic Analysis, 1985; Table on New Housing Construction.

housing typically takes six months to a year from permit to potential occupancy, there are currently a total of 3.5 million new housing units (i.e., < 24 months). The Statistical Abstract of the United States (1985) indicates that the average household contains 2.73 individuals (Table 58). Multiplied together, a total of 9.6 million people currently are potentially at risk of lead contamination in their drinking water from newly-installed lead solder.

Combined, at least 38.1 million people (lower bound: 30.4 million)* using public water supplies currently receive water that exceeds the proposed MCL. We consider this a low estimate because:

- we have not considered the potential exposure of occupants in housing built within the past 2-5 years (who probably remain at greater risk of elevated lead levels);
- many samples in the data base were taken from the distribution system and not from within a private residence (biasing the results downwards);
- at least two data sources may contain biases that underestimate exposure; and
- our data are from running samples, while many people consume water that is closer to standing samples (and which most likely contains higher concentrations of lead).**

In addition, we have not included any data from the 30-40 million users of private and non-community water supplies which, because those systems are not covered by the SDWA, need not

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* This analysis includes only an estimate and a lower bound. Our data do not provide a basis for an upper bound estimate.

** Water that has been standing in pipes has a greater opportunity for lead to leach into it and, therefore, is more likely to contain higher lead levels.

comply with EPA's drinking water standards and monitoring requirements (and so may be more likely to have higher contamination levels).

Our estimates of the health benefits associated with this proposed rule rely on the data collected for the Second (U.S.) National Health and Nutrition Examination Survey (NHANES II), a 10,000 person representative sample of the U.S. non-institutionalized population, aged 6 months to 74 years. That data base is available from the (U.S.) National Center for Health Statistics and data from it have been published often (e.g., Annest et al., 1980 and 1982; Mahaffey et al., 1982; Pirkle and Annest, 1984).

Our assumptions on the relationship between water lead levels and blood lead levels are taken from the Water Criteria Document for Lead (1985). That document assumes a linear relationship, with different constants for children and adults. Those formulae are:

(for children) PbB* = 0.16** x intake of lead from water

(for adults) PbB* = 0.06** x intake of lead from water

Alternative assumptions (e.g., Richards and Moore, 1982 and 1984) could indicate that we have underestimated exposure -- and consequently underestimated benefits -- by a factor of 3-5.

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* PbB = blood lead level

** These constants have a unit of micrograms-of-lead/deciliter-of-blood per microgram-of-lead-in-water/day, or ug/dl per ug/day.

2. Benefits of Reducing Children's Exposure to Lead

Elevated blood-lead levels have long been associated with neurotoxicological effects and many other pathological phenomena: an article on lead's neurotoxicity was published as early as 1839, on anemia in the early 1930s, on kidney damage in 1862, and on impaired reproductive function in 1860. From an historical perspective, lead exposure levels considered acceptable for either occupationally-exposed persons or the general population have been revised downward steadily as more sophisticated biomedical techniques have shown formerly-unrecognized biological effects, and as concern has increased regarding the medical and social significance of such effects. In the most recent downward revision of maximum safe levels, the Centers for Disease Control (CDC) lowered its definition of lead toxicity to 25 micrograms of lead per deciliter of blood (ug/dl, the standard measure of blood lead level) and 35 ug/dl of free erythrocyte protoporphyrin (FEP). The present literature shows biological effects as low as 10 ug/dl (for heme biosynthesis) or 15 ug/dl (for renal system effects and neurological alterations); indeed, some effects (e.g., elevated levels of a potential neurotoxin* or stature effects, Angle et al., 1982; Schwartz et al., 1986, etc.) have exhibited no threshold so far.

There is no convincing evidence that lead has any beneficial biological effect in humans (Expert Committee on Trace Metal Essentiality, 1983).

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* ALA, or aminolevulinic acid.

Elevated blood-lead levels have been linked to a wide range of health effects, with particular concern focusing on young children. These effects range from relatively subtle changes in biochemical measurements at 10 ug/dl and below, to severe retardation and even death at very high levels (80-100 ug/dl). Lead can interfere with blood-forming processes, vitamin D metabolism, kidney function, neurological processes and reproductive functions in both males and females. In addition, the negative impact of lead on cognitive performance (as measured by IQ tests, performance in school, and other means) is generally accepted at moderate-to-high blood-lead levels (30 to 40 ug/dl and above), and several studies also suggest cognitive effects at much lower levels; changes in electroencephalogram readings, for instance, are detectable at levels as low as 10 ug/dl. For many subtle effects, our data represent the limits of detectability of biochemical or other changes, and not thresholds for effects.

For children's health effects, we estimated two categories of benefits: medical care for children exceeding the lead toxicity level set by the Centers for Disease Control (25 ug/dl, when present in combination with FEP levels > 35 ug/dl) and cognitive effects. We developed two alternative methods for valuing the potential cognitive damage resulting from exposure to lead. The first of these two alternatives involves assessing the costs of compensatory education to address some of the manifestations of the cognitive damage caused by lead as a proxy measure for the damage itself. The second relates to one specific indication of that cognitive damage -- potential IQ point loss,

and includes a calculation of decreased expected future earnings as a function of IQ point decrement. These estimates are conservative because, for instance, they do not include many major categories of pathophysiological effects (e.g., renal damage), nor do either the medical costs or the compensatory education costs consider any lasting damage not reversed by medical treatment or compensatory education, nor do they attribute many benefits to reducing lead levels in children whose blood lead levels would be below 25 ug/dl even in the absence of the rule.

To estimate reductions in medical care expenses, we used published recommendations (Piomelli et al., 1984) for testing and treating children with blood lead levels above 25 ug/dl. Such treatment, we estimate, costs about $950 per child over 25 ug/dl (1985 dollars). (This average reflects lower costs for most of these children, but much higher costs for the subset requiring chelation therapy.)

The estimates for compensatory education assumed three years of part-time compensatory education (de la Burde and Choate, 1972 and 1975) for 20 percent of the children above 25 ug/dl, averaging about $2,800 per child above that blood lead level (1985 dollars), based upon data from Kakalik et al., 1981.

There is extensive literature examining the relationships between schooling, IQ, demographic variables and earnings (ICF, 1984). We used the results of that literature to calculate the effect of the IQ point losses that can occur as a part of the cognitive damage caused by lead exposure upon expected future earnings: one IQ point can directly and indirectly affect earnings

by 0.9 percent. The studies of cognitive damage presented in the Air Quality Criteria Document for Lead (U.S. EPA, 1986) show evidence that blood lead levels of 15-30 ug/dl can be associated with IQ losses of 1-2 points, blood lead levels of 30-50 ug/dl can be associated with IQ losses of 4 points, and over 50 ug/dl of blood lead can correlate with losses of 5 points. We used data from the Census Bureau on expected future lifetime earnings, deferred for 20 years* at a 5 percent real discount rate, and then annualized the potential damage to yield estimated benefits benefits from reduced exposure to lead. This alternative method for valuing some of lead's cognitive damage indicated that the U.S. could save $1,040 per child brought below 15 ug/dl; $2,600 per child brought below 30 ug/dl; and $2,850 per child brought below 50 ug/dl by reducing lead in drinking water (1985 dollars).

In sum, this proposed rule will produce benefits of $7.7 million annually in avoided medical expenses; $22.7 million per year in reduced compensatory education costs; and $151.7 million per year in increased lifetime earnings, based upon sample year 1988; these estimates are in 1985 dollars. Note that compensatory

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* These costs are deferred because those suffering the effects are children and will not enter the work force for up to 20 years. Obviously, using the largest deferral period (20 years) reduces the value of the benefit and reduces our benefit estimate, whereas 8-or 10-year-old children may begin working within 8 years and so would have a much shorter deferral period. This biases our estimates downward.

education and affected earnings are alternative methods for valuing aspects of the cognitive damage caused by lead.*

In addition, there are two other categories of health effects (lead's adverse affect upon children's growth and potential fetal effects) that we did not monetize. However, this rule could prevent 36,400 children from growth decrements and 622,000 fetuses from being exposed to potentially dangerous lead levels. The fetal effects are particularly important, because several recent studies have shown lead levels associated with various negative pregnancy outcomes (e.g., Moore, 1982; Wibberly et al., 1977), with inhibited post-natal growth and development (e.g., Bornschein, 1986; Bellinger, 1985 and 1986; Dietrich et al., 1986), and even with Sudden Infant Death Syndrome (Erickson et al., 1983).

3. Blood-Pressure-Related Benefits and Other Adult Health Effects

Lead has long been associated with elevated blood pressure, but until recently most of the studies have focused only on hypertension and relatively high lead levels typically found only in those occupationally exposed to lead. Several recent studies, however (e.g., Pirkle et al., 1985; Harlan et al., 1985; Pocock, 1984 and 1985), have found a continuous relationship between blood lead and blood pressure, and show a strong relationship that has proved robust in the face of exhaustive statistical tests involving many possible confounding factors and alternative

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* This is a conservative assumption. There is a strong rationale for seeing these effects as additive.

specifications of the model. These recent studies may help to explain the inconsistent findings of association in analyses conducted over the past 30 years on the relationship between soft water and cardiovascular disease rates (cf. Comstock, 1985).

To calculate the benefits of reduced lead exposure, we used logistic regression equations to predict how an MCL of 20 ug/l would affect the number of hypertensives. These estimates cover only males aged 40 to 59, because the effect of lead on blood pressure appears to be strongest for men and because estimates for that age range are not confounded by a strong covariance between age and both blood pressure and blood lead. Our estimates rely upon data from the NHANES II and cardiovascular disease coefficients from the Framingham Study (McGee et al., 1976) and Pooling Project (1976), as confirmed by Levy et al., 1984.

We estimate that the rule will reduce the number of male hypertensives between the ages of 40 and 59 by 118,400 in 1988. We valued reductions in hypertension based on estimates of the costs of medical care, medication, and lost wages; they yielded a value of $250 per year per case of hypertension avoided (1985 dollars).

We also estimated how reductions in blood pressure would affect the incidences of various cardiovascular diseases, based on our projections of changes in blood pressure as a result of the rule and estimates of the relationships between blood pressure and heart attacks, strokes, and deaths from all causes. The latter estimates were derived from several large epidemiological

studies, primarily the Framingham study. Because those studies included very few nonwhites, we further restricted our estimates to white males aged 40 to 59. The basis of most of the medical costs is presented in Hartunian et al., 1981. We adjusted the cost-of-illness estimates contained there in three ways to reflect current conditions. First, we inflated them to 1985 dollars using data from the 1986 Economic Report of the President to Congress. Second, we adjusted the costs to reflect changes and improvements in treatment, including the tripling in the incidence rate of coronary bypass operations that occurred between 1975 and 1982. Third, Hartunian used a 6 percent real discount rate to present value future expenditures, while our analysis uses a 10 percent real discount rate.

We valued reductions in heart attacks and strokes based on the cost of medical care and lost wages for nonfatal cases (the fatalities from heart attacks and strokes were included in the estimate of deaths from all causes). That procedure yielded benefits of $65,000 per heart attack and $48,000 per stroke avoided (1985 dollars) for the 370 heart attacks and 75 strokes avoided in 1988 because of this proposed rule. It is important to note that these estimates do not account for any reductions in the quality of life for the victims of heart attacks and strokes (e.g., the partial paralysis that afflicts many stroke victims).

Valuing reductions in the risk of death is difficult and controversial, with a wide range of estimates in the literature. EPA's policy guidelines (U.S. EPA, 1984), for example, suggest a range of $400,000 to $7 million per statistical life saved. For

our point estimate, we used a value from the lower end of that range, $1 million per case. The benefits of reduced mortality dominate our estimates of total blood-pressure-related benefits, and total $370 million in 1988 for the 370 avoided deaths in that year. Altogether, the monetized benefits of reducing adult male exposure to lead by reducing the MCL for lead in drinking water total $427.3 million per year (in 1985 dollars), using 1988 as a sample year.

In addition, because lead crosses the placental barrier and is a fetotoxin, pregnant women exposed to lead are at risk of complications in their pregnancies and damage to the fetus. Among these adverse effects are higher miscarriage rates and spontaneous abortions (fetal effects are discussed above, under children's health effects). While we have not monetized any of these reproductive effects, 622,000 pregnant women per year probably receive water that exceeds the proposed standard of 20 ug/l, and would benefit from the proposed rule. Lead-induced effects on male reproductive functions have also been discussed in the scientific literature but are not included in this report.

4. Benefits of Reduced Materials Damage

A third category of monetized benefits relates to the phenomenon of lead's presence in drinking water: it is a product of the corrosive action of water upon the materials of the distribution and residential plumbing. For the most part, therefore, treatment processes used to reduce high levels of lead in drinking water are the same as treatment processes used to reduce the corrosion potential of the water. Reducing corrosion damage will produce substan-

tial benefits to water utilities, their rate-paying customers, and building owners.

Published estimates of the costs of corrosion damage range from $12 to $46 per person per year (1985 dollars), and are summarized on Table 2. Estimates of the costs that can be avoided by corrosion control measures range from 20-50 percent of total damage. Our point estimate of avoidable corrosion costs (i.e., the benefits of corrosion control) is $8.50 per capita annually (1985 dollars). For comparison, estimates of average corrosion treatment costs range from under $1 per person per year (based upon the experience in Boston and Seattle, cities currently treating their highly corrosive waters) to almost $5 per person per year (based upon the highest treatment costs presented in the ODW cost report).* As a point estimate, we assumed per capita annual treatment costs of $3.80 (1985 dollars).

Estimates of the extent of corrosive water also vary. The most commonly accepted profile is that developed by the U.S. Geological Survey in the early 1960s, which identified the Northeast, Southeast, and Northwest sections of the country as having the softest and most corrosive waters (Durfor and Becker, 1964a and 1964b). The combined populations of those states are 49.6 million people (1980 census). That figure, multiplied by $8.50 per person, yields annual benefits from reduced corrosivity of $421.6 million (1985 dollars).

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* The range, however, is quite wide and highly sensitive to system size. These represent average costs. In some very small systems (i.e., serving 25-100 people), costs may be many times higher.

TABLE 2. Estimates of Annual Per Capita Corrosion Damage (1985 dollars)

Studies	Estimated Annual Corrosion Damage (per capita)			Corrosion Damage Avoidable Through Water Treatment	Annual Per Capita Benefits of Corrosion Control	Assumptions/Notes
	Distribution Systems	Residential	Total			
Kennedy Engineers (1973)	$5.57	--	$16.71*	30%*	$5.01*	We assumed 30% potential reduction in corrosion damage and that distribution costs were one-third of total costs.
Hudson & Gilcreas (1976)	$8.68*	--	$26.04*	50%	$13.02*	They did not include increased operating costs. Per capita estimate assumes 200 million people are served by public water systems. We assumed that distribution costs were one-third of total costs.
Kennedy Engineers (1978)	--	$30.87*	$46.30*	20%	$9.26*	They calculated $6.17 per capita in savings to residence owners. We assumed residential costs were two-thirds of of total costs.
Bennett et al. (1979) (cited in Ryder, 1980)	$9.40	--	$28.20*	20%	$5.64*	We assumed that 200 million people are served by public water systems and that distribution costs were one-third of total costs.
Energy & Environmental Analysis (1979)	$3.98	$7.97	$11.95	38%	$4.54	This is an admitted underestimate: it includes only damage to pipes.
Ryder (1980)	$1.17	$22.19	$23.36	25%	$5.84	Ryder ascribed 95% of corrosion damage to private owners
Kirmeyer & Logsdon (1983)	--	$23.60*	$35.40*	40%	$14.16*	We assumed residential costs are two-thirds of total damage.
					AVERAGE $8.21 W/OUT EEA $8.82	

* These estimates have been calculated by the authors of this paper based upon assumptions that are not included in the published articles.

5. Summary of Benefits of Reduced Lead in Drinking Water

Our analysis of reducing the MCL for lead from 50 ug/l to 20 ug/l indicates that the monetized annual benefits are large: $879.3 to $1,008.3 million (1985 dollars) for sample year 1988 (lower bound: $806.2 to $889.7 million). In addition, there are numerous health benefits of reduced exposure to lead that we have not monetized. The annual monetized benefits are summarized in Table 3, and the non-monetized benefits are presented in Table 4.

Based upon the latest cost estimates used by the Office of Drinking Water (USEPA, 1984),* the benefits exceed the costs by 7:1 (using the lower-bound estimate of occurrence, also 7:1). Expressed differently, lowering the MCL to 20 ug/l will produce annual net benefits of about $800 million in 1988 (using the lower-bound estimate of occurrence, $700 million).

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* These calculations use preliminary EPA Office of Drinking Water cost estimates. Costs and net benefits will be discussed more extensively in other documents associated with this rulemaking.

TABLE 3. Summary of Annual Monetized Benefits of Reducing the Lead MCL from 50 ug/l to 20 ug/l (1985 dollars) for Sample Year 1988

Estimated population exposed to drinking water exceeding proposed MCL	38.1 million* (lower bound: 30.4 million)
Children's health benefits	
-reduced medical costs	$7.7 million
-reduced costs of cognitive damage	
Method 1 - compensatory education	$22.7 million
Method 2 - decreased future earnings	$151.7 million
TOTAL: Method 1	$30.4 million
Method 2	$159.4 million
Adult health benefits (males only)	
-reduced hypertension savings (males, aged 40-59)	$29.6 million
-savings from fewer heart attacks (white males, aged 40-59)	$24.1 million
-savings from fewer strokes (white males, aged 40-59)	$3.6 million
-savings from fewer deaths (white males, aged 40-59)	$370.0 million
TOTAL:	$427.3 million
Materials benefits	
-benefits of reduced corrosion damage	$421.6 million
TOTAL ANNUAL MONETIZED BENEFITS	
-Method 1 - using compensatory education	$879.3 million (lower bound: $806.2 million)
-Method 2 - using decreased future earnings	$1,008.3 million (lower bound: $889.7 million)

* Total population served by community water systems: 219 million

TABLE 4. Summary of Annual Non-monetized Benefits of Reducing the Lead MCL from 50 ug/l to 20 ug/l for Sample Year 1988

	Reductions in Numbers of People at Risk
Estimated population exposed to drinking water exceeding proposed MCL	38.1 million* (lower bound: 30.4 million)
Children's health benefits	
- children requiring medical treatment	8,100
- loss of 1-2 IQ points	142,000
4 IQ points	1,500
5 IQ points	23
- children requiring compensatory education	8,100
- children at risk of stature decrement	36,400
- fetuses at risk	622,000
- increased risk of hematological effects	36,400
Adult health benefits	
-cases of hypertension (males, aged 40-59)	118,400
-heart attacks (white males, aged 40-59)	370
-strokes (white males, aged 40-59)	75
-deaths (white males, aged 40-59)	370
-reduced risk to pregnant women (women, aged 15-44)	622,000
-reduced risk of reproductive effects (women, aged 15-44)	34,000

* Total population served by community water systems: 219 million

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ECONOMIC EFFECTS OF REDUCED FOREST GROWTH ON THE UNITED STATES' FOREST ECONOMY AND ON CANADIAN-U.S. LUMBER TRADE

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ABSTRACT.

Several recent studies have reported both localized and region-wide decreases in the radial growth rates of several commercially important forest species in the eastern half of United States. These observed reductions in tree growth rates may be related to increases in acid deposition and other man-made air pollutants over the last three decades. In the first part of this study, we review the evidence regarding these reductions in forest growth and, using economic theory, show how these physical changes can impact the production and purchasing decisions of buyers and sellers in timber and primary wood product markets. We then show how standard willingness-to-pay principles can be used to place monetary values on the physical damages caused by air pollution, due to these changes in the behavior of economic agents in affected markets. In the second part of the study, we describe how this information about changes in tree growth can be used in conjunction with existing inventory projection and timber market models to simulate the potential economic effects of acid deposition/air pollution in the United States. Two sets of simulations are conducted. The first set assumes that air pollutants generated in the United States do not damage Canadian forests. The second set of simulations attempts to take into account the potential effects of reduced growth in Canadian forests due to air pollutants generated in the United States and/or Canada. These damages are simulated by increasing Canadian stumpage fees in the Canadian lumber supply functions contained in the timber market model used in the analysis. The final part of the study presents the results of the simulations, quantifying the potential economic effects of acid deposition in the United States and to a limited extent, Canada. Specific attention is focused on the effects of different assumptions regarding the magnitude and geographic distribution of reduced tree growth on timber inventories, stumpage prices and harvest levels, lumber and plywood production and prices in the United States, and on Canadian lumber exports to the U.S. Estimates of the effects of reduced tree growth on the welfare of timber owners and the buyers and sellers of lumber and plywood in the United States are presented, along with information about changes in the welfare of lumber producers in Canada. These results suggest that if increases in Canadian stumpage fees (as a government response to transboundary pollution damage) are not too great, Canadian lumber producers and exporters may actually earn higher profits because of increased demand from the United States for Canadian lumber exports. While

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Canadian consumers would be hurt by higher prices, quantitative effects on this sector and on Canadian timber owners could not be computed due to modeling constraints.

1. INTRODUCTION

This paper has three objectives: 1) to describe the methodological framework that was developed for the United States' National Acid Precipitation Program (NAPAP) to assess the range of potential economic impacts that could occur due to air pollution-induced reductions in forest growth in the eastern United States; 2) to present the results of that analysis, prepared for the 1985 Damage Assessment; and 3) to explore the potential effects of reduced forest growth in the United States and Canada on exports of lumber from Canada to the United States and on the economic well-being of Canadian lumber producers. To meet these objectives, the paper is divided into three major sections. The remainder of Section 1 provides background information about NAPAP and the goals of the 1985 Damage Assessment. It also presents evidence for concern about possible slowdowns in forest growth in the eastern United States. Finally, Section 1 shows how standard willingness-to-pay principles can be used to place monetary values on the physical damages caused by air pollution. Section 2 describes the methodological framework and simulations that were developed to assess the economic impacts of simulated reductions in forest growth, while Section 3 presents the results of these simulations. Finally, Section 4 summarizes the findings of this study.

1.1. NAPAP 1985 Assessment-Overview

NAPAP was created by the Acid Precipitation Act of 1980 (Title VII of the Energy Security Act, P.L. 96-294). Planning for NAPAP commenced in the fall of 1980 and a final plan was completed, after extensive public review, in the summer of 1982. This was supplemented in 1984 by a more detailed Operating Research Plan [1] which called for the execution of several assessments, the first scheduled for 1985, to evaluate the causes, effects and damages resulting from acid deposition. Responsibility for conducting these assessments was specifically given to the Assessments Task Group (Task Group I), which is one of 10 working groups organized within the NAPAP programmatic organization.

The NAPAP 1985 Assessment possessed at least two important characteristics that distinguish it from subsequent, integrated assessments. First, the 1984 NAPAP plan [1] specifically charged Task Group I with estimating the magnitude of the current physical and economic damages caused by acid deposition phenomena in the 1985 Assessment, whereas subsequent assessments were to examine the benefits of (or damages reduced by) specific control options. An important aspect of the damages-oriented focus of the 1985 Assessment that needs to be stressed is that the preliminary damage estimates reported in this study may not be the same as the benefits of control policies for regulating the precursors of acid deposition. The damage estimates contained in the 1985 Assessment assume fairly pristine environmental conditions which are not necessarily consistent with economic efficiency objectives. In general, information about the incremental benefits of various control options must be integrated with information about incremental control costs to determine economically efficient levels of damage reduction.

Second, the 1985 Assessment was regional rather than national in its geographic scope. The information necessary to conduct a national-level assessment is not yet available. Given this limitation, the regional focus of the 1985 Assessment was directed largely toward the Eastern half of the United States, where monitored deposition levels are higher, on average, than in other parts of the country and where research on the physical effects of acid deposition has been concentrated. Four types of receptor systems, potentially sensitive to gaseous air pollutants and acid deposition, were included in NAPAP's economic analysis.

These were crops, forests, aquatics, and materials. These areas were selected based on scientific and public concern about the possible physical effects of acid deposition [1]. For consistency with economic methods and data bases only the following areas were subjected to analysis: commercial agriculture; commercial forests; recreational fishing; and common building, cultural and infrastructure materials. The remainder of this paper focuses specifically on the research performed to estimate the potential economic impacts of air pollution in the eastern U.S. on timber and selected primary wood product markets in the nation as a whole.

1.2. Evidence of Growth Slowdowns in the Eastern U.S.

Recent studies have reported both localized and region-scale decreases in the growth rates of several commercially-important forest species in the eastern U.S. Red spruce decline in high elevation was first reported by Siccama et al. [2] in the Green Mountains of Vermont. Evidence included a decrease in the basal area growth rate and density of 50% between 1965 and 1980 and the presence of visible symptoms such as needle loss. Reduced growth was found in all observed age classes. Similar evidence of red spruce decline, including increased mortality, has been observed in other areas of the high elevation northeastern and southeastern forests [3] with the symptoms seeming to increase with elevation. The association between growth slowdowns and high elevation is important because air pollution concentrations and deposition tend to increase with elevation. In addition to the studies of growth slowdowns in high elevation forests, growth slowdowns have been detected in low elevation forests [4]. However, the conclusions in this study are based on changes in tree ring growth, which is generally regarded as less certain than the visible symptoms observed in high elevation spruce.

Another source of evidence that Eastern forests may be experiencing a reduction in growth rates is the periodic analysis of timber inventories in the Southeastern United Sates conducted by the Forest Service's Southeastern Forest Experiment Station (FIA analysis). The most recent FIA analysis indicates that the annual growth rates of softwood timber have declined over a fairly large geographic area compared to the previous FIA analysis [5]. For example, the radial growth of yellow pines in the Piedmont Region and mountains of Georgia was 20-30% less between 1972 and 1982 than between 1961 and 1972. Further investigations indicate that radial growth rates of most yellow pines under 16 inches in diameter declined by between 30 and 50% throughout the Piedmont, Mountain, and Coast Plain Regions of the Southeast.

A number of causes have been proposed for the growth rate reductions in the Southeast. In addition to air pollution, these causes include: 1) aging of stands, 2) increased stand density, 3) increased hardwood competition, 4) drought, 5) diseases, and 6) changes in land use. It is not possible, at present, to determine which of the above potential effects might have caused the changes in growth rates. The hypothesis that acid deposition, one of several candidates, caused the growth slowdowns cannot be accepted or rejected with present scientific information. For that reason, we do not attempt to link our analysis to acid deposition. Our model and analysis is are general; the changes in growth rates are hypothetical and could be due to any cause. However, the results presented in Section 4 are based on growth reductions that are consistent with those reported by the U.S. Forest Service [5].

In view of the inconclusive nature of the information about the physical effects of acid deposition, it would be wrong to assume that one can accurately project the effects of acid deposition or acid deposition controls on stumpage and forest product markets in the United States. However, it would also be incorrect to assume that economic analysis of acid deposition damages has nothing to contribute to acid deposition-related research at this time. Specifically, the research presented in this paper can serve as a basis for

characterizing the potential scope of the economic impacts of acid deposition and for assessing the sensitivity of the simulated economic impacts of acid deposition to different assumptions about the nature of the potential physical effects of acid deposition on tree growth. Under no circumstances should the results presented in this paper be viewed as forecasts about the future economic impacts of acid deposition.

1.3. Valuing Damages

Two different approaches can be used to evaluate the economic damages of air pollution-induced decreases in forest growth [6]. The first is the so-called damage function approach. This technique uses dose-response functions to translate changes in air pollution levels into physical damages. Physical damages are then multiplied by a unit economic value, such as a market price, to obtain a measure of economic damages.

For example, if the effects of acid deposition on the annual growth increments for different size trees of a particular species in a given location were known, the impact of this effect on the total inventory volume for that species could be calculated on an annual basis. The projected annual change in the inventory could then be multiplied by a projected stumpage price for each year of the projected life of the current inventory to obtain annual estimates of the future damages of acid deposition to the subject species. Discounting these values at an appropriate measure for the opportunity cost of capital and then summing these values for each year in the projection period would provide a measure of the present value of the damages caused by acid deposition to the species in question. Repeating these steps for all commercially-important species on all acres of commercial timberland would result in an estimate of the present value of the aggregate damages of current levels of acid deposition in commercial timberland.

These are several shortcomings associated with applying the above approach, or variants of it, to measure the economic value of the damages caused by current levels of acid deposition or other air pollutants. For example, the damage function approach can sometimes be used to approximate the economic losses of producers of goods and services and, in some cases, the economic damages suffered by owners of natural resources, such as timberland. However, this approach does not capture the effects which acid deposition may have, indirectly, on firms which process stumpage into lumber, plywood, paper and a large number of other products or on the consumers who purchase goods and services that contain wood products. A second problem is that it ignores substitutions which individuals and firms can make in their consumption and production decisions due to changes in prices. Generally speaking, extremely unrealistic assumptions have to be made about the preferences of individuals, the technology of firms, and the structure of the markets being analyzed for the damage function approach to yield damage measures which are consistent with economic theory.

A second approach overcomes these shortcomings by using mathematical representations (models) of supply and demand curves in appropriate markets to characterize the behavior of consumers and producers. Information about the direction and magnitude of environmental impacts is generally used in conjunction with this approach to shift the relevant supply or demand curves in affected markets to simulate the behavioral responses of consumers and producers. Appropriate damage measures can then be evaluated from these simulated shifts in supply and demand curves. This approach is illustrated in Figure 1, which characterizes price (P) and output (Q) determination in a market for stumpage, given market demand and supply curves D, S for stumpage. The wel fare of consumers (e.g. buyers of stumpage) can be approximated [7] by the

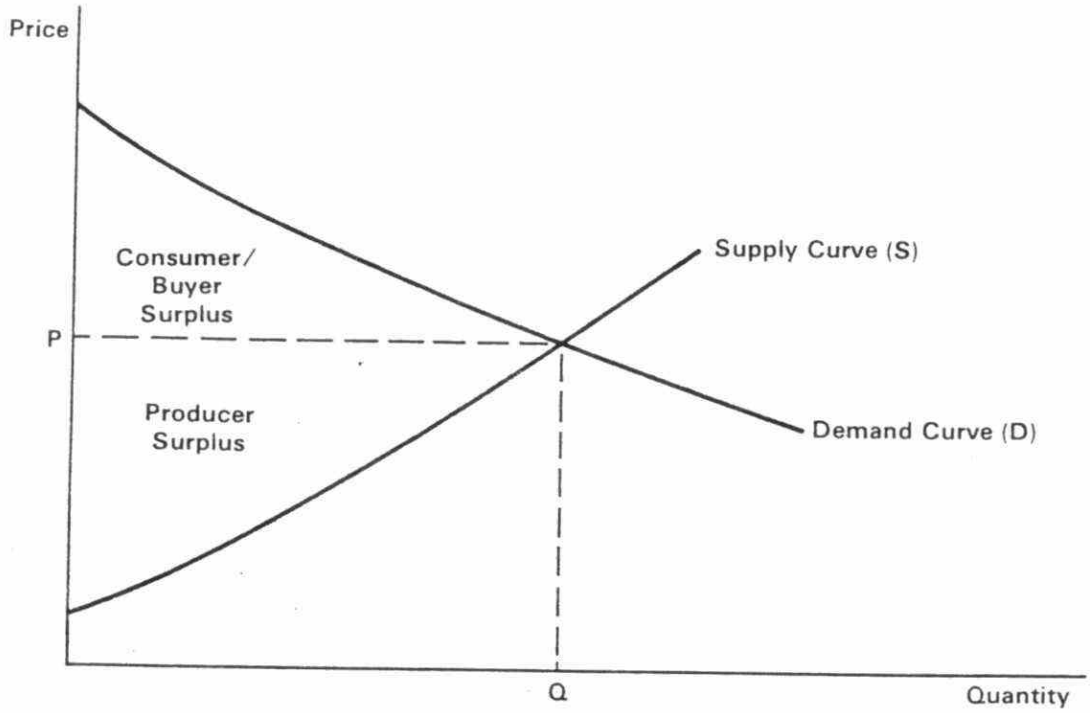

FIGURE 1
Price and output determination in a stumpage market.

area underneath the market demand curve and above the price line, drawn horizontal from P. This area, known as consumer or buyer surplus, is equal to the maximum amount individuals are willing to pay for a single unit of stumpage less the amount actually paid. Producer surplus measures the welfare of timber owners in the market (e.g. producers of stumpage). It is given by the area above the market supply curve and below the price line. This area is equal to the difference between the amount received by timber owners from the sale of stumpage less the minimum cost of producing Q units of stumpage. Total surplus in the market is approximated by the sum of these two areas.

Figure 2 shows how information about market supply and demand curves can be used to value economic damages due to acid deposition. The physical affects of acid deposition are shown here by the inward shift of the market supply curve for stumpage from S to S'. This type of effect is consistent with the movement of the market supply curve for a commercial stumpage in response to reduced yields. This change results in a higher market price (P') and reduced output (Q'). The reduction in total surplus in the stumpage market is approximated by the shaded area between the two supply curves and represents the measure used to value the damages of reduced tree growth on buyers and sellers in commercial stumpage markets. A similar type of analysis can be performed in forward markets to determine damages to the consumers of the forward products of stumpage such as lumber and plywood.

2. TECHNICAL APPROACH

The economic effects of hypothetical reductions in tree growth were simulated using modified versions of the softwood and hardwood forest sector models, TAMMSOFT [8] [9] and TAMMHARD [10], and a forest inventory projection model, TRAS [11] [12], to which the economic models are physically linked. A brief description of these models and a discussion of how they were used to assess the economic impacts of reduced tree growth follows.

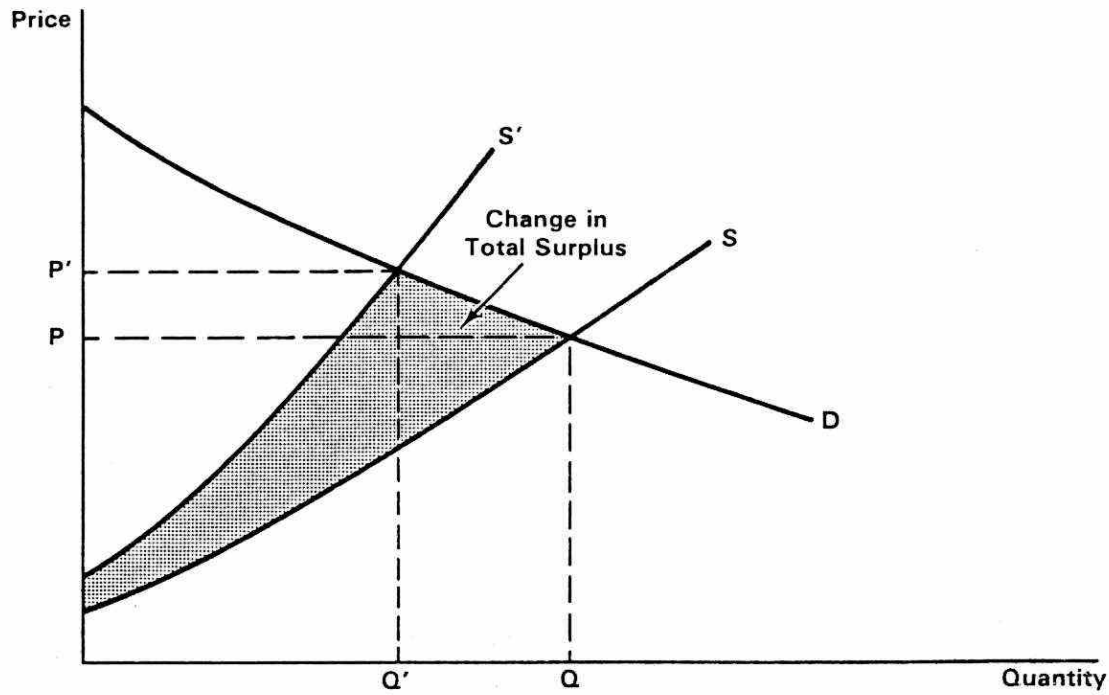

FIGURE 2
Measurement of economic damages due to acid deposition.

2.1. Models

The basic function of TRAS is to provide the TAMM models with information about the size of the growing stock inventory of trees which is potentially available for harvesting within each region. TRAS represents regional inventories as aggregate per-acre stands of trees, broken down by two species groups (hardwoods and softwoods) and two ownership groups (forest industry and nonindustrial private). The trees in each of the four representative stands are further divided into eleven two-inch diameter classes. Given user-specified values for annual radial growth and natural mortality in each of these classes and for the number of new trees in the smallest diameter classes, TRAS calculates the annual change in the number of trees in each diameter class. TRAS does this by first estimating the potential increase in the number of trees within each diameter class in the absence of natural mortality and harvesting. Annual net growth is then calculated for each class by subtracting natural mortality. Harvest levels are calculated by the TAMM models for each species and owner group in each region. TRAS allocates these removals to different diameter classes and subtracts them from the remaining inventory of trees to determine the annual change in the number of trees in each diameter class. This change is used in conjunction with the beginning inventory of trees to update the inventory of trees in each diameter class. TRAS then repeats this cycle on an annual basis to maintain the proper accounting balance within the regional inventory.

TAMMSOFT and TAMMHARD are multi-market, spatial equilibrium models of the softwood and hardwood stumpage and primary forest products industries in the United States. TAMMSOFT contains six domestic demand regions in which final products are consumed and eight domestic supply regions in which timber is harvested and three wood products-lumber, plywood, and pulp-are produced. TAMMHARD contains one national consuming region and four domestic supply regions in which stumpage is harvested and lumber and pulp are produced. Physical linkages between

the hardwood and softwood models are accomplished through a common pulpwood supply sector physically located in TAMMSOFT. The method of linking the two models is unique to this assessment and is discussed in detail in Callaway et al. [13].

In both models each region has either demand or supply equations, as appropriate, for lumber and plywood. Product and stumpage markets in each region are linked together. The regional supply equations for each final product are specified so that the amount of each product supplied in a region is sensitive to changes in both the final product price and the price of softwood and hardwood stumpage. Aggregate stumpage demand is derived directly from product supply by a series of conversion factors. The conversion factors can be adjusted to reflect the effects of technological change on the efficiency of processing lumber and plywood. The stumpage supply equations in each of the producing regions in the models reflect the harvest response of forest industry and nonindustrial private owners to changes in stumpage prices and inventories. The latter information is supplied to both models directly from TRAS. Finally, a spatial equilibrium solution is calculated in both stumpage and product markets within the models for each year in the projection period 1976-2030.

TAMMSOFT also contains a Canadian supply region in which lumber is produced for export to the United States. Total Canadian softwood lumber production is modeled as a function of producer's profit margin, which is the difference between the softwood lumber price and the sum of delivered wood costs and lumber manufacturing costs. Delivered wood costs are related functionally in each period to Canadian softwood lumber production in the previous period and a time trend. Canadian domestic demand for lumber and lumber exports to countries other than the United States are determined exogenously, which prevented the computation of effects on Canadian consumers of changes in lumber prices. The Canadian stumpage sector also is not modeled explicitly in TAMMSOFT. Canadian softwood lumber production, softwood lumber exports to the United States, and Canadian softwood lumber price are all determined endogenously as a part of the spatial equilibrium solution generated by the linked system of models.

The system of models described above produces annual information about the size, species and ownership composition of the growing stock inventory of trees on commercial timberland in each region. It also provides information on an annual basis about regional stumpage prices and harvest levels, regional commodity prices, output levels, and consumption in lumber and plywood markets. Finally, the TAMM models were modified for this study to provide welfare measures of consumer and producer surplus that are theoretically consistent with a spatial equilibrium in a vertically integrated market chain [14] [15]. For this study, total welfare changes due to hypothetical reductions in tree growth were represented by changes in the sum of: 1) consumer surplus of the buyers of lumber and plywood, 2) producer surplus of the producers of lumber and plywood, and 3) the producer surplus of timberland owners.

2.2. Methods

Two sets of simulations were performed. The first set of simulations was conducted to examine the effects of hypothetical changes in tree growth rates in the Eastern United States on growing stock inventories, stumpage and primary products markets, and the welfare of buyers and sellers in these markets in the United States. This set of simulations assumes that air pollutants generated either in Canada or in the United States do not damage Canadian forests. For the second set of simulations it was assumed that Canadian forests would be damaged by air pollution generated in the United States or Canada. These simulations explore the effects of reduced tree growth in both the United States

and Canada on the export trade between the two countries and on the welfare of Canadian lumber producers. The methods used in connection with both sets of simulations are described below.

First, base case values for appropriate economic impact variables and welfare measures were established by running the system of models for the period 1985-2030. Base case assumptions regarding key driver variables in TAMM and TRAS are, for the most part, identical to those used by the U.S. Forest Service [16] and reported by Haynes and Adams [9]. Major assumptions include: 1) future housing starts at 1.7 million units in 1990, 1.9 million units in 2000, and 1.5 million units in 2030; 2) a 10% increase in the efficiency of processing lumber and plywood during the projection period; and 3) 319 million acres of commercial timberland remaining in 2030. The initial inventories contained in TRAS, as well as the radial growth rates of timber used in the base case, are also identical to the growth rates used by the U.S. Forest Service [16].

The second step of the analysis involved adjusting relevant parameters within the TAMM and TRAS models to simulate reduced tree growth. For the first set of simulations, hypothetical reductions in tree growth were simulated by reducing the radial growth rates that are used by TRAS to calculate the annual net growth of trees from one diameter class to the next for both hardwoods and softwoods. Since data to provide appropriate guidance about the magnitude and distribution of recently-observed growth slowdowns by species and by diameter class are not yet well developed, uniform growth rates changes across species and all diameter classes were assumed. Accordingly, the annual radial growth rates in TRAS were uniformly reduced in the Northeast and Southeast timber supply regions* by 10,15, and 20%. These growth rate reductions are generally smaller in magnitude than those reported by Sheffield et al. [5] for several pine species in the southeastern United States. However, there is considerable speculation that perhaps as much as a half of the observed change in radial growth among softwoods in the southeast can be explained by natural phenomena, such as increased stand density and increasing competition with hardwoods. If that is the case, then the radial growth rate changes used in this analysis may represent a realistic, but nevertheless hypothetical, range of air pollution effects.

Simulating reduced tree growth in Canadian forests is complicated by several factors. First, very little is known about the effects of long-range pollution on Canadian forests. Second, the response of public timberland owners in Canada (who own the majority of Canadian timberland) to reduced forest growth is difficult to predict. Finally, and in a more practical vein, the Canadian stumpage sector is not modeled explicitly in TAMM. In spite of these problems, we believe that characterizing the effects of reduced forest growth in both the U.S. and Canada on the timber trade between the two nations, if only on a preliminary basis, represents a worthwhile policy exercise. In keeping with that belief, we simulated the effects of reduced tree growth in Canada and the U.S. by increasing the intercept in the Canadian delivered wood cost functions in TAMMSOFT by $1.00, $2.00 and $3.00 (U.S. 1967) for each of the three reduced growth cases in the U.S. These adjustments have the effect of shifting the Canadian lumber supply curve inward in each year. This is consistent with the effects of an increase in the price of Canadian stumpage which could be the result of either air pollution-induced market adjustments or market-oriented public policies.

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* The Northeast includes Connecticut, Delaware, Maine, Maryland, Massachusetts, New Hampshire, New Jersey, Pennsylvania, Rhode Island, Vermont, and West Virginia; the Southeast includes Florida, Georgia, North Carolina, South Carolina, and Virginia.

In the third step of the analysis, the system of models was rerun for the period 1985 to 2030 for each of the reduced growth cases identified above. All other driver variables were left unchanged from the base case. The resulting values for appropriate economic impact variables were recorded and the difference between the base case values and the values obtained using the revised tree growth rates were attributed to the effects of a particular reduction in tree growth. Finally, the annual value of the economic damages for each reduced growth case was calculated as the difference between the net present value of total estimated welfare for the period 1985-2030 with and without the growth rate change. The total damage estimate for each reduced growth case was annualized (i.e., levelized) using a 10% real discount rate.

3. RESULTS

This section presents the results of the simulations described in Section 2. Sections 3.1 to 3.4 focus on the effects of simulated reductions in tree growth rates in the eastern United States (only) on growing stock inventories, prices, and output levels in both stumpage and lumber markets and on the welfare of buyers and sellers in these markets. Finally, Section 3.5 covers the effects of simulated reductions in tree growth in Canada and the United States on the lumber trade between Canada and the United States.

3.1. Impacts On Growing Stock Inventories

Table 1 compares the TAMM Base Case projections of combined softwood and hardwood growing stock inventories in the year 2030 with the inventory projections associated with simulated reductions in tree growth rates of 10, 15 and 20%. Three aspects of the simulated effects of reduced timber growth on commercial timber inventories deserve attention. First, the projected decrease in the Southeast timber inventory in all three reduced growth cases is approximately twice as great as the projected decrease in the Northeast inventory. This is due to the composition of the growing stock inventory in the Southeast, which contains a relatively larger share of young, fast growing trees than the Northeast. Reducing the growth rates of these trees causes a larger and longer lasting decrease in total inventory volume than does reducing the growth rates of older, slower growing trees. Second, reducing tree growth rates in the Northeast and Southeast causes timber inventories in other supply regions to decrease by roughly 3.5 to 10.0% depending on the magnitude of the timber

TABLE 1
Percentage Changes in Combined Softwood and Hardwood Growing Stock Inventories Due to Simulated Reductions in Radial Growth in the Northeast and Southeast: 2030 Forecasts.

Region	Base Case (Billion Cubic Feet)	Growth Rates in the Northeast and Southeast Reduced by 10%, 15%, and 20% (Percentage Change from Base) 10%	15%	20%
Northeast	112.48	-8.63	-13.47	-19.09
Southeast	125.11	-20.54	-29.21	-38.28
Other Supply Regions	239.26	-3.45	-6.05	-10.08
Total U.S.[a]	476.85	-9.16	-13.88	-19.60

(a) Includes only the lower 48 states.

growth rate reductions in the two eastern regions. This is an induced effect of reduced tree growth in the eastern U.S., which leads to an improvement in the comparative cost advantage of other supply regions in the interregional trade for lumber and plywood. The improved competitive position of these regions (relative to the two eastern regions) leads to higher lumber and plywood production, larger harvest levels and smaller inventory volumes than in the Base Case.

Third, the direct and induced effects of reduced tree growth rates on projected timber inventories for the U.S. as a whole range from about 10 to 20%, depending on the case selected. One way to place these effects in perspective is to compare these inventory changes with those due to insect pests and disease. Callaway et al. [13] have estimated that the physical effects of a 15% growth reduction of timber in the Northeast and Southeast are roughly comparable to the physical damage caused by insect pests and disease on all eastern commercial timberland.

3.2. Impacts On Stumpage Markets

Table 2 shows the effects of simulated reductions in timber growth rates on the combined softwood and hardwood harvest levels projected by TAMM for the year 2030. As expected, the size of the combined softwood and hardwood harvest for the U.S. as a whole decreases from the Base Case levels as the magnitude of the simulated timber growth rate reduction is increased. The percentage decreases in the combined harvest are small (i.e., less than 1.5% in the most severe reduced growth case) because smaller harvests in the Northeast and Southeast are offset somewhat by larger harvests in the other supply regions. Projected stumpage prices for 2030 (not shown) are higher in all regions when timber growth rates were increased in the two eastern regions. For example, projected softwood stumpage prices range from 4 to 9% above Base Case levels in the Northeast and 12 to 25% higher than Base Case levels in the Southeast. In the Pacific Northwest, which is an important competitor in softwood lumber and plywood markets, softwood stumpage prices are from 14 to 25% higher than Base Case values, depending on the severity of the growth reduction.

To understand these results a distinction should be made between stumpage price increases in regions directly affected by growth reductions and price increases in other regions. In the first case, stumpage price increases are accompanied

TABLE 2
Percentage Changes in Combined Softwood and Hardwood Harvests Due to Simulated Reduction in Radial Growth in the Northeast and Southeast: 2030 Projections.

Region	Base Case (Billion Cubic Feet)	Growth Rates in the Northeast and Southeast Reduced by 10%, 15%, and 20% (Percentage Change from Base) 10%	15%	20%
Northeast	3.09	-3.24	-4.53	-6.15
Southeast	5.02	-6.22	-11.16	-14.81
Other Supply Regions	13.42	1.94	3.72	4.62
Total U.S.[a]	21.53	-0.71	-0.93	-1.46

(a) Includes lower 48 states for softwood and Eastern U.S. only for hardwood.

by smaller harvests. As the productivity of growing stock inventories in regions directly affected by growth reductions declines, harvestable stumpage becomes more scarce. In response to this increased scarcity, timberland owners are willing to sell stumpage only if they receive higher prices. These higher prices, however, increase the costs of producing lumber and plywood, so manufacturers of these products reduce both their output levels and their purchases of inputs, i.e., stumpage. The net effect is to increase stumpage prices and reduce harvest levels in those regions directly affected by reduced growth.

In regions where timber growth remains unchanged, both stumpage prices and harvest levels increase. Even though manufacturers of lumber and plywood in regions directly affected by growth reductions reduce their output, they still must sell their products at higher prices if they are to recover the higher production costs caused by higher stumpage prices. Higher product prices in the two eastern regions increase the competitiveness of lumber and plywood produced in other regions where growth rates remain unchanged. Manufacturers of these products in other regions, therefore, increase both their output levels and their purchases of stumpage inputs. As a result, stumpage prices and harvest levels in other regions rise.

3.3. Impacts On Product Markets

Table 3 shows the impacts of simulated reductions in timber growth rates on projected production of hardwood and softwood lumber (combined) in the U.S. and on imports of Canadian softwood lumber for the year 2030. The same general patterns that were present in domestic stumpage markets are also observed for this one, but representative, product market. That is: projected production levels in the Northeast and Southeast are lower than in the Base Case, while lumber production in other regions is slightly higher than in the Base Case. The net result is a decrease in domestic lumber production ranging from about 3 to 7%, depending on the magnitude of the growth reduction. There is, however, a substantial increase in imports of Canadian softwood lumber which partially offsets this decrease: even in the "worst" case the total of U.S. lumber production plus Canadian imports is less than 3.5% below the Base Case level.

TABLE 3
Percentage Changes in Combined Softwood and Hardwood Lumber Supplies Due to Simulated Reductions in Radial Growth in the Northeast and Southeast: 2030 Projections.

Source of Combined Lumber Supply by Region	Base Case (Billion Board Feet)	Growth Rates in the Northeast and Southeast Reduced by 10%, 15%, and 20% (Percentage Change from Base)		
		10%	15%	20%
Northeast[a]	3.41	-1.76	-2.93	-4.40
Southeast	12.17	-21.53	-29.74	-35.91
Other Supply Regions	36.48	2.88	3.07	2.08
Total U.S.[b]	52.06	-3.13	-4.99	-7.22
Imports of Canadian Softwood Lumber	9.62	8.21	12.27	16.84

(a) Softwood lumber supplies in the Northeast are price inelastic in TAMM.
(b) Includes lower 48 states for softwood and Eastern U.S. only for hardwood.

In view of the vertical linkages which exist between stumpage and wood product markets and the horizontal trade linkages between regions in both plywood and lumber markets, these results are not so surprising. As previously mentioned, simulated reductions in tree growth rates in the eastern U.S. confer a comparative cost advantage on lumber and plywood producers in other supply regions. As a result, regions directly affected by these growth reductions reduce lumber and plywood production and either import a larger, or export a smaller, quantity of wood products in each period. Producers in other supply regions tend to increase their output of lumber and plywood either to increase their exports to, or reduce the volume of imports from, those regions directly affected by the simulated reductions in tree growth rates. Since increased production causes the demand for stumpage to increase in other supply regions, input costs and product prices in these regions also rise until a new trade equilibrium is established.

A similar process occurs at the international level. As prices of wood products in the U.S. rise, the nation exports fewer and imports more wood products. This pattern is reflected primarily in the growth of Canadian imports of lumber into the U.S. By distributing the impacts of timber growth reductions in one or two regions over a broader geographical area and a larger number of producers, these changes in domestic and international trading patterns tend to cushion the decreases in total U.S. output of wood products which might otherwise occur.

3.4. Welfare Impacts

Table 4 gives estimates of the effects of simulated reductions in tree growth on the economic surplus of timber owners, lumber and plywood producers and the buyers (consumers) of these products. As previously stated, these estimates represent changes from Base Case values in the annualized net present value of each of the relevant economic surpluses, cumulated over the period 1985 to 2030. In aggregate terms, these estimates reflect the value of the economic damages which can be attributed to the simulated timber growth rate reductions over the period. These damages, shown in the last row of Table 4, ranged from about $340 to $510 million annually, depending on the severity of the hypothetical growth reduction. These damages are always small in comparison to the Base Case--always less than 1.0% of the roughly $70 billion total surplus estimate. The corresponding changes in the net present value of damages over the entire period (not shown) are roughly $3.4, $4.4 and $5.0 billion.

The distributional impacts of the assumed growth reductions are shown in the first three rows of Table 4. In general, timber owners as a group benefit from reductions in radial growth due to their ability to pass along higher prices to

TABLE 4

Estimated Changes in the Annualized Economic Surplus of Timber Owners, Lumber and Plywood Producers and Consumers Due to Simulated Reductions in Radial Growth in the Northeast and Southeast (millions of 1984 dollars).

Economic Group	Base Case Surplus	Growth Rates in the Northeast and Southeast Reduced by: 10%	15%	20%
Timber Owners	5,603.8	63.4	109.9	220.7
Producers	23,887.6	-63.4	-40.4	148.0
Consumers	40,178.2	-342.4	-516.3	-878.8
Total	69,669.6	-342.4	-446.8	-510.1

the producers of primary wood products. The annualized benefit received by timber owners was estimated to range from about $60 to $220 million. The picture for producers of primary wood products is mixed. As a group, they experience annual damages in the 10 and 15% reduced growth cases of $60 and $50 million but receive roughly $150 million in annual benefits when radial growth is reduced by 20%. Of the three groups, consumers of wood products bear the brunt of the damages due to simulated reductions in radial growth. The decreases in economic surplus of this group ranged from about $340 to $880 million annually. Moreover, a substantial portion of these losses represent transfers of economic surplus from consumers to producers and timber owners as physical damage levels were increased.

Table 4 does not present a geographic breakdown of economic damages. However, timber owners in the southeast suffer economic damages due to all growth slowdowns. In addition, producers in that region are hurt considerably more by these changes in growth than producers in the Northeast, who actually experience slight benefits. This suggests a relative (but not absolute) improvement in the competitive position of the Northeast over the Southeast due to decreased tree growth in both regions.

3.5. Impacts on Canadian Lumber Trade

Previously, in Table 3, we saw that Canadian exports of softwood lumber to the U.S. in 2030 increased with the severity of simulated forest damage in the eastern U.S. We now examine how robust this result is in the face of simulated increases in the delivered cost of softwood to Canadian lumber producers.

Table 5 shows how average annual exports respond to simulated decreases in radial growth in the eastern U.S. and to simulated increases in Canadian delivered wood costs during the period 1985-2030. Holding the change in Canadian delivered wood costs constant at four specified levels (i.e., $0.00, $1.00, $2.00 and $3.00), we can read down each column to see how Canadian lumber exports to the U.S. respond to simulated forest damage in the eastern U.S. In all four cases involving changes in Canadian delivered wood costs, the volume of average annual softwood lumber exports to the U.S. increases with the magnitude of the growth reduction in the U.S. However, when the change in radial growth in the eastern U.S. is held constant, one can see by reading across each row that this pattern is reversed. In all but two cases, an increase in Canadian delivered softwood costs results in a decrease in the volume of average annual softwood lumber exports to the U.S.

TABLE 5

Effects of simulated reductions in radial growth in the Eastern U.S. and simulated increases in Canadian delivered wood costs on average annual exports of Canadian softwood lumber to the U.S. 1985-2030 (billion board feet).

Growth Rate Change--U.S. (pct. decrease)	Increase in Canadian Delivered Softwood Costs (1967 U.S. Dollars)			
	Base	$1.00	$2.00	$3.00
Base	10.70	10.57	10.41	10.24
10	11.10	10.87	10.57	10.54
15	11.24	10.97	10.51	10.80
20	11.68	11.03	10.60	10.89

Figure 3 illustrates how air pollution-induced increases in U.S. and Canadian stumpage prices influence exports of Canadian softwood lumber to the U.S. using a simple two-region trade model. Initially, we assume no air pollution damage to either U.S. or Canadian forests. Under this assumption, S_0 units of lumber are produced in Canada at a price of P_0. Canadian lumber consumption is fixed at D (as is the case in TAMM), so that Canadian lumber exports to the U.S. are equal to S_0-D.

If we now assume that air pollution damages U.S. forests (only), then the resulting increase in U.S. stumpage prices would cause the U.S. lumber supply curve in Figure 3 to shift inward. This leads to an increase in the U.S. demand for Canadian lumber at the new market price P_1. Canadian lumber production increases accordingly to S_1 and, now, S_1-D units of lumber are exported from Canada to the U.S. Note that, in the process, the producer surplus of Canadian lumber producers increases by an amount equal to the area between P_1 and P_0 above the initial Canadian supply curve.

If we assume that acid deposition also damages Canadian forests, the subsequent increase in Canadian stumpage prices would induce an inward shift in the Canadian lumber supply curve, as shown in Figure 3. This chain of events leads to an increase in the trade price of lumber from P_1 to P_2 and a decrease in Canadian lumber production from S_1 to S_2. Canadian lumber exports to the U.S. also fall by the same amount. Note, however, that lumber exports as depicted in Figure 3 are still greater than they were in the initial case, when forests in both countries were experiencing no air pollution damage. But this result is just one of two possible outcomes. Had the Canadian lumber supply curve in Figure 3 been shifted further inward, both Canadian lumber production and lumber exports to the U.S. would have fallen below initial levels indicated by

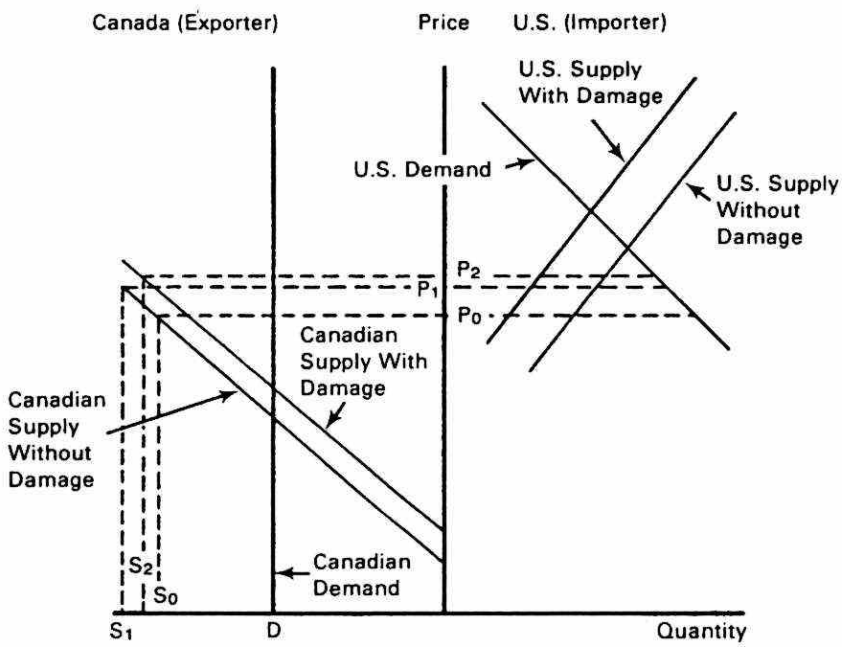

FIGURE 3
Effects of air pollution-induced stumpage price increases in the U.S. and Canada on U.S.-Canadian softwood lumber trade.

S_0. Thus, the eventual effect of air pollution on Canadian lumber production and exports to the U.S. depends: 1) on the relative movement of the two supply curves as a result of increased stumpage prices and 2) on the curvature of the lumber supply and demand curves in both regions in the neighborhood of the price-quantity changes which take place.

The effect of joint increases in stumpage prices in both regions on the producer surplus of Canadian lumber producers is also difficult to determine on a priori grounds. This is because there are basically two counteracting forces at work. Increases in Canadian stumpage prices lead to higher wood costs and lower profits. However, higher trade prices lead to increased revenues and higher profits. The net effect of these two forces on the producer surplus of Canadian lumber producers depends on the same two factors which influence changes in the volume Canadian lumber production and lumber exports to the U.S.

Table 6 shows how the annualized value of the producer surplus of Canadian softwood lumber producers responds to simulated forest damage in the Eastern U.S. and to increases in Canadian delivered softwood costs. Consistent with the previous discussion, it can be seen that, when the change in delivered wood cost is held constant, the annualized producer surplus of Canadian lumber producers generally increases. This result does not appear to hold at the highest damage level where higher lumber profits in the U.S. trigger increased domestic lumber production capacity within TAMM.

One reason why these damages are not greater is that simulated reductions in tree growth rates in the eastern U.S. allowed lumber and plywood in other regions, including Canada, to become more competitive with eastern producers. As a result, economic activity in both stumpage and primary wood product markets in these other regions increased and thus buffered the adverse effects of reduced timber growth in the nation as a whole. This general pattern was not affected by increases in the intensity of simulated timber growth reductions.

Table 6 also shows that the welfare of Canadian softwood lumber producers, as measured by changes in producer surplus, generally decreases in response to increases in Canadian delivered softwood costs. As we pointed out earlier, this is due to the fact that increases in delivered wood costs cause softwood lumber production costs to rise more rapidly than the increase in lumber revenues due to higher trade prices. On balance, the results from Table 6 suggest that as long as increases in Canadian stumpage prices due to air pollution damages are not too great, Canadian lumber producers may actually benefit from air pollution damages in the U.S. and earn higher profits than under pristine environmental conditions. Although the effect of increased prices on the

TABLE 6

Effects of simulated reductions in radial growth in the Eastern U.S. and simulated increases in Canadian delivered wood costs on the value of the annualized producer surplus of Canadian lumber producers (millions of 1984 dollars)

Growth Rate Change--U.S. (pct. decrease)	Increase in Canadian Delivered Softwood Costs (1967 U.S. Dollars)			
	Base	$1.00	$2.00	$3.00
Base	1166.9	1141.6	1116.3	1087.3
10	1195.3	1175.2	1146.3	1126.4
15	1255.1	1241.0	1228.5	1192.5
20	1250.4	1196.9	1143.4	1175.8

welfare of Canadian consumers is unambiguously negative, no computations could be done of the size of the effect.

4. SUMMARY

In this paper we described the framework which was developed for the 1985 Damage Assessment to assess the economic impacts of air pollution-induced decreases in forest growth in the eastern United States. The evidence for concern about the potential effects of air pollution and, more specifically, acid deposition on forest growth was presented. The fact that recently observed decreases in tree growth rates in the eastern United States cannot be linked scientifically to increases in acid deposition was stressed. Therefore, the results of this study should not be viewed as forecasts of the economic consequences of increases in acid deposition. Rather the results are intended to characterize the potential scope of the economic impacts of acid deposition and to test the sensitivity of these impacts to different assumptions about the intensity of the potential physical effects of acid deposition on tree growth.

We estimated the effects of hypothetical reductions in tree growth rates in the eastern United States of 10, 15 and 20% on growing stock inventories, stumpage and primary wood product markets and on the economic welfare of buyers and sellers in these markets. The estimated annual damages due to hypothetical reductions in tree growth for the period 1985-2030 ranged from approximately $340 to $500 million, depending on the severity of the simulated growth reduction. These damages represent a small (less than 1%) fraction of the combined annual economic surplus of timber owners and the producers and is that simulated reductions in tree growth rates in the eastern United States allowed lumber and plywood producers in other regions, including Canada, to become more competitive with eastern producers. As a result, economic activity in both stumpage and primary wood product markets in these other regions increased and thus buffered the adverse effects of reduced timber growth in the nation as a whole. This general pattern was not affected by increases in the intensity of simulated timber growth reductions.

We also looked at the responsiveness of Canadian softwood lumber exports and the producer surplus of Canadian softwood lumber producers to simulated forest damage both in the U.S. and Canada. Generally speaking, we found that softwood lumber exports to the U.S. increased with the severity of simulated forest damage in the U.S., but decreased in response to simulated increases in Canadian delivered wood costs. The producer surplus of Canadian softwood lumber producers generally followed the same pattern. Overall, the results of this analysis suggest that, as long as Canadian forest damages are not too severe, Canadian producers may well be the beneficiaries of air pollution damages and could earn higher profits than under pristine environmental conditions. Comparable calculations could not be done for Canadian consumers or timber owners.

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SOME ECONOMICS OF THE GRAND CANAL

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Comments are invited.

SOME ECONOMICS OF THE GRAND CANAL

1. Introduction

In recent years the popular press has paid considerable attention to the GRAND Canal scheme advocated by Kierans (1985) and others. The scheme calls for the conversion of all or part of James Bay into a freshwater lake which would accumulate run-off from northern rivers in Ontario and Quebec. The water would be pumped south to the Great Lakes via the Harricanaw, Ottawa, and French Rivers from whence it could be diverted at several points to augment water supplies in the United States. A combination of inflows from the north and outflows to the south would permit stabilization of water levels in the Great Lakes, particularly Lakes Huron and Michigan. The water exported to the United States would supplement scarce regional supplies for urban and agricultural use.

The plan has been unfavourably received in many quarters. Newspaper reports and editorials (e.g. Toronto Star, 23 May 1985, Globe and Mail, 3 Jan 1985) have stressed potential environmental and political costs. The Inquiry on Federal Water Policy (The Pearse Inquiry) devoted a chapter to Water Exports and concluded that the federal government should resist pressures to support any large scale international diversion scheme, at least until the Cabinet has determined under what conditions, if any, major water export schemes might be approved and until legislation is in place to conduct thorough assessments of all proposals and to license the water exports (Chapter 12). The Minister of the Environment has declared that, at present, he is opposed in principle to the project (MacMillan, 1986).

Nevertheless, the scheme has attracted serious attention both in the public and private sectors. Premier Bourassa (1985) of Quebec strongly promoted studies of the concept in his book published shortly before his election. Four large Canadian engineering firms, SNC and Rousseau, Sauve and Warren of Montreal, Bechtel Canada, and the UMA group of Calgary have formed a joint venture with the GRAND Canal Co. of St. John's to carry out engineering and other studies of the scheme. This group has applied for $763,000 through the National Research Council (NRC) and the Department of Supply and Services to fund the major portion of the cost of preparing a "project statement" which would form the basis of subsequent proposals for private and public funding. Despite the strong opposition of much of the federal bureaucracy, NRC seems committed to providing financial assistance to the GRAND Canal Company.[1] NRC's argument seems to be that the proposal is a far-sighted one with potential merit and that federal funds should be provided to help the GRAND Canal Co. better understand both the costs and benefits of the project.

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1 Letter from Keith Glegg, Vice-President Technology Transfer, National Research Council, to Hon. Charles Caccia, 13 January 1986.

We are thus faced with a proposal which is regularly dismissed out of hand by most federal authorities, yet which persists on the policy agenda. Further pursuit of the proposal is likely to involve substantial expenditures of public and private funds which, given current fiscal restraint, should be carefully husbanded. Accordingly, it seems useful to attempt to lay out some basic issues surrounding the proposal in the hope of directing public discussion towards the central issues in dispute.

Following the suggestion of Scott (1985), the discussion will be organized in the economic framework of Cost-Benefit Analysis. In a paper prepared for the Inquiry on Federal Water Policy, Scott argued vigorously that this approach provides a systematic procedure for ensuring that water development proposals are shaped so as to provide the maximum net advantage to the country. A definitive cost-benefit analysis is, of course, out of the question in the absence of much more detailed information about the project. Nevertheless, the discipline involved in formulating the problem in terms of costs and benefits aids in deciding whether the project is at all viable and, if so, in identifying the areas in which detailed information is most urgently required.

The next section of the paper presents the case made by the proponents of the GRAND Canal project and the major objections which have been raised against it. The following section examines more systematically the costs and benefits associated with the project. Where information is available, an attempt is made to develop rough estimates of their magnitude. A number of fallacies to avoid in estimating benefits are discussed. A final section summarizes and concludes the paper.

2. The Project

As argued by Kierans (1985), the case for the GRAND Canal rests on the recognition of four major water quantity issues. These are

(a) A shortage of water on the Canadian prairies

(b) Fluctuations in water levels and impending water shortages in the Great Lakes-St. Lawrence basin.

(c) Impending shortages of water for agricultural, industrial and urban use in the United States, especially the mid- and south-west.

(d) The need to avoid diversions of northward flowing rivers so as not to foreclose options for northern development.

According to Kierans, these problems would all be mitigated by the GRAND canal scheme. Very large volumes of water could be delivered to the Great Lakes for transmission to the Canadian West and the American mid-west and south-west, thus alleviating problems (a) and (c). Because the inflow and outflow of water from Lakes Michigan and Huron would be controlled, the level of these lakes could be stabilized, thus addressing problem (b). Finally, since none of the rivers flowing into James Bay would be diverted before it reached the ocean, problem (d) would be solved.

Kierans claims that the scheme will promote large increases in North American agricultural and industrial production. He claims support from the experience of recycling of freshwater from the IJselmeer in Holland and from the delta of the Sacramento River in California. Both projects are alleged to have generated very large benefits. Canada would capture some part of the benefits accruing to the United States through payments made by American authorities for the exported water.

Kierans also claims that the scheme would have many additional benefits. Among these are the stabilization of the James Bay shoreline, the creation of employment, the provision of a new network of electric power generating stations, and improved trade between Canada and the United States.

Opposition to the proposal has taken many forms. It is argued that water shortages in the United States and Canada can be alleviated through demand management (i.e. a reduction in the demand for water through conservation and diversion from lower valued uses) backed by rational water pricing. Alternatively, water exports are opposed on the grounds that the water will be required in Canada in the future. A water export scheme is seen as irreversible for all intents and purposes. Many environmental costs are to be expected from the construction and operation of such a project. These include possible changes in climate, biological damage through the transfer of harmful organisms across watersheds, and destruction of the recreational potential of some river valleys. Finally, social costs may be imposed on native peoples and others who could be displaced from traditional pursuits or whose communities could be disrupted by the booms and busts characteristic of resource development.

In the next section we examine the potential costs and benefits of the GRAND Canal project in more detail. To do so we must consider a specific variant of the proposal, while recognizing that the outcome of our analysis might be altered if a different variant were chosen. Indeed one of the virtues claimed for cost-benefit analysis is that it encourages optimization of proposals during the process of evaluation.

The proponents of the GRAND Canal have not committed themselves to any specific form of the project. Kierans (1985) simply states that eventually up to 20% of the natural runoff into James Bay would be made available for recycling and that the cost of facilities to impound James Bay water and deliver it to the Great Lakes would be of the order of $50 billion. No specific volume of water is mentioned. Informal calculations by other engineers suggest that the cost of such a system would be substantially higher, perhaps of the order of $130 billion (before allowance for interest during construction).

Basing our discussion on such informal calculations, we assume a maximum total diversion of 100,000 cfs (708 m^3/s) from James Bay with delivery (after evaporation losses) of 75,000 cfs to Georgian Bay. This water would be available to compensate for firm withdrawals from Lakes Superior, Michigan or Erie (see DeCooke, Bulkley and Wright (1984) for a discussion of possible

routes) and for augmentation of natural flows to Lake Michigan-Huron in dry years. In the latter case provision must be made for discharge of larger than normal volumes during wet years. The south-western United States and western Canada thus obtain water in two forms: a guaranteed flow and an interruptible flow whose mean value depends on the variance of natural discharges into the Great Lakes. Presumably guaranteed flows would have a higher value to the receiving regions but would reduce benefits from water level stabilization on the Great Lakes.

The GRAND Canal scheme is only one of several large scale water diversion schemes which have been proposed in the past. Others include the North American Water and Power Alliance (NAWAPA) and the Central North American Water Project (CeNAWP) to divert waters from as far north as the MacKenzie river to the United States via the Rocky Mountain Trench and the Canadian Prairies respectively. (See Scott (1985, 29ff.) for discussion). Any serious evaluation of the GRAND Canal scheme would have to compare all three possibilities, as well as other ways of meeting water shortages, to a benchmark alternative. The benchmark adopted in this paper is continued reliance on natural drainage to the Great Lakes and no further diversions from them.

3. Costs

Table 1 sets out the main categories of costs and benefits associated with the GRAND Canal scheme and provides very rough estimates of some of them. The most important categories are capital cost of the project itself, the annual operating costs, the opportunity cost of the water, and finally environmental and social costs incurred during construction or operation of the project. The following paragraphs consider each category in more detail.

Capital and Operating Costs

Total capital costs are heavily influenced by the cost of constructing a dam across some fraction of James Bay. The remaining major item is the cost of construction of pumping stations: this cost varies with the designed capacity of the project. Table 2 reports a range of estimates of the total capital and operating cost. Case 3 represents Kierans's (1985) estimate of $50 billion. Cases 1 and 2 are drawn from informal engineering calculations. Case 1 considers a diversion of 2832 m^3/s (100,000 cfs) representing somewhat less than 25% of the estimated total run-off to James Bay. The volume of water transmitted is comparable to Case 3. Case 2 considers "recycling" virtually all the run-off from James Bay. Since the cost of the containing structure is the same in both examples, the estimated average cost falls sharply in the larger project.

To the direct cost has been added interest during the 15 years of construction. The conclusions hold for a wide range of interest rates. Interest during construction was calculated on the assumption that costs are evenly spread over the construction period. If costs are in fact more heavily concentrated at the end of construction, interest costs would be lower. A social discount rate of 8% has been adopted for the analysis presented here.

The total capital cost has been expressed as a lump sum as of the date of completion and as the equivalent annual payment required to amortize this sum over the hypothesized 80 year life of the work.

Annual operating and maintenance costs are dominated by the energy cost of pumping the water. This energy should be evaluated at its true social opportunity cost, namely the higher of its full cost of production (if it is produced by dedicated power generating stations) or the foregone revenue and consumers surplus from displaced consumption by domestic consumers and export customers.

Unquantified Costs

A number of costs have not been quantified in Table 1. Among these are the opportunity cost of the water exported and environmental costs incurred during construction and operation of the project. Information is not readily available about these costs, but some of them may be large.

The water that would be committed for export under the GRAND Canal scheme has alternative uses. In particular, it could be left to drain to James Bay as it normally does or it could be diverted to other final destinations, including the Canadian prairies. The value it would have in these uses is its opportunity cost.

If one excludes the social and environmental costs discussed below, the opportunity cost of the GRAND Canal water is probably low. The willingness of western Canada to pay for additional water supplies will not be significantly greater than the willingness of the South-west United States, and significant costs would be incurred in delivering the water from the Great Lakes to them. Nevertheless, should the GRAND Canal preempt the sale and delivery of James Bay water to Western Canada, the foregone revenues should be included as a cost of the project.

More significant are the environmental and social costs which might be caused by undertaking the project. Environmental effects of the project would include modification of the ecology of the James Bay coast and possible climatic changes due to the earlier freezing of the Bay. Unless new canals were built for the entire route to Georgian Bay, natural water courses would be submerged and subject to flooding. Some of these, for example the French and Mattawa Rivers, have high historic and recreational values. Moreover, many people place high value on the mere existence of water in its undisturbed natural state (Muller, 1985). The strong negative public reaction to the GRAND canal scheme indicates that the willingness to pay to avoid the scheme might be high. No cost-benefit analysis of the project would be complete without an attempt to gauge the magnitude of these costs.

Another set of costs should also be considered. Large construction projects generate considerable employment, but much of it is temporary. The boom and bust cycle generates social costs if migration of labour leads to high expenditures on housing and other social infrastructures which must later be abandoned. It may also disrupt the social structure of small northern

communities. Full compensation for these losses should be accounted a cost of the project. Because relatively few people are involved, however, the total cost of compensation may not be very large.

In Table 1, no entry has been made for the opportunity cost of water, nor for the social and environmental costs of construction and operation. Some evaluation of these costs would be required before the GRAND Canal project could ever be allowed to proceed.

3. Benefits

As shown in Table 1, the main benefits claimed for the GRAND Canal can be grouped into the benefits of increased consumption of water, benefits from stabilization of water levels on the Great Lakes, the generation of power, and the provision of employment. Before considering them individually, some general comments on the measurement of benefits will be useful.

Economic Impacts versus Economic Benefits

Proponents of the GRAND Canal sometimes argue that one should not take a "user pay" approach to evaluating the benefits of the project, but should rather assume that only a small fraction of the total benefits of a water project are captured by the end user. As an example they cite studies such as Milliken's (1979) evaluation of the economic impact of the California Central Valley irrigation scheme and the study by Kulshreshtha and others (1985) of the impacts of irrigation projects in Alberta and Canada generally. The latter study, for example, claimed that only 15% of the total benefits of irrigation projects in Alberta accrue to the water users while 66% accrue to other Albertans and 19% to the rest of Canada. If the same ratio applied to benefits of water distributed from the Great Lakes, the total willingness to pay for water in the South-western United States would range up to $666 Canadian per thousand cubic metres[2], a figure comparable in magnitude to the total cost of delivering such water.

Such an argument is fundamentally wrong because it confuses economic <u>impacts</u> with economic <u>benefits</u>. The Kulshreshtha paper, for example, uses the terms interchangeably. It calculates the economic impact of irrigation by comparing the predicted level of gross domestic product (GDP) for Alberta in a world with and without the presence of irrigated agriculture using the techniques of input-output analysis.

The economic <u>impact</u> of an activity is legitimately measured by this technique. By the impact of an activity is meant the change induced in selected economic indicators (such as GDP, employment, or public revenues) as a result of the activity. It is assumed that if the activity were not undertaken, nothing would take its place. Thus, for example, Kulshreshtha <u>et.al.</u> have apparently compared the output of the Alberta economy with

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2 100/.15 = 666

irrigated agriculture with an economy in which the net output of irrigated produce is zero but the net output of all other industries is the same as before.[3]

The economic impact may be divided into direct, indirect and induced effects. The direct effect is the change in output of the irrigated agriculture. The indirect effects are the increased levels of intermediate production required to support that output. One can also calculate an induced effect, caused by allowing the final consumption of other goods and services to expand as the economy grows. These impacts induced effects are often called multiplier effects.

The economic benefit of an activity is the gain realized by undertaking it. We say that a project is worth undertaking when its benefits exceed its costs. Accordingly benefits should be measured by the amount people would be willing to pay to obtain them. The economic impact of a project is not a good measure of what people would be willing to pay for the project for two reasons.

First, in calculating the impact of an activity such as irrigation, one implicitly assumes that the land, labour, capital and materials used have no alternative use. This is patently false. Even in an underemployed economy, many of the resources released from a declining industry find employment elsewhere. Thus, for example, the benefit received by labour from irrigation in Alberta is not measured by wages received in irrigation, but by the excess of wages received in irrigated agriculture over the amount that would have been received elsewhere. The economic impact of an activity overstates the benefits received from it to the extent that there are alternative uses for the resources employed in the activity.

Second, in calculating the impacts of a project, one frequently uses a "closed" input-output model to calculate induced effects. This procedure is equivalent to using the Keynsian multiplier discussed in elementary Economics texts. Problems arise because, as most economists now agree, the Keynsian multiplier is at best a short run phenomenon. In the longer run, the multiplier is reduced as other economic activities are crowded out by higher prices and interest rates. Rather than the multipliers of 1.7 and higher implied by input-output models, most large-scale econometric models of the Canadian economy show multipliers that decline from slightly over one in the first year of an activity to close to zero after ten years. This implies that the long run impact on GNP of any sustained government expenditure is close to zero. Thus the multipliers used in many economic impact analyses greatly overstate the true increase in GNP associated with an activity or project.

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3 Alternatively, they may have increased the output of dryland agriculture by the estimated value of dryland crops which could be grown on the lands that are presently irrigated. The essence of the following argument is unchanged.

To summarize, the benefits of the GRAND Canal project cannot be measured by economic impact analysis, but only by the willingness of recipients to pay for more water. As we shall see, this willingness to pay appears to be low. We now consider individually each of the benefits claimed for the GRAND Canal.

Revenue from Water Exports

The benefits to Canada from exporting water beyond the Great Lakes Basin would be realized in the form of payments negotiated with various agencies in the United States. Since the United States will attempt to gain some net benefit from the water deal, these payments cannot exceed the total willingness of the United States to pay for additional water at the Great Lakes. The correct way to calculate a maximum willingness to pay (WTP) for water delivered to the Great Lakes is to estimate the willingness of end users to pay for additional water and then to deduct additional costs incurred in transporting the water beyond the Great Lakes. The result may overestimate total WTP if water from other sources can be delivered more cheaply.

Most evidence indicates that most end users of water are not willing to pay very much for additional volumes. Muller (1985) summarized estimates of the WTP for water in Canada for a number of uses. One must be careful in interpreting such data, since the methods and concepts underlying the various estimates may not be comparable. Nevertheless, irrigation uses were valued in the range of $19 to $36 Canadian per thousand cubic metres (at 1984 prices). U.S. studies cited by Veeman (1985, 57) implied values in the south-western United States as high as $69 Canadian per thousand cubic metres. Willingness to pay for water in industrial uses ranged from $19 to $124 Canadian per thousand cubic metres. Only municipal use had a potential value well above these figures. These figures must be viewed as highly tentative, since most are based on updating cost data from quite old studies.

The total cost of delivering water from the Great Lakes to the US South-west is estimated to be about 10 times greater than these WTP values. For example, DeCooke, Bulkley and Wright (1984, 14) estimate an average cost of $577 per acre foot (about $710 per thousand cubic metres - date and currency unspecified) to deliver water from the Great Lakes to the Ogallala reservoir. Clearly neither irrigators nor any other class of user in the US South-West (with the possible exception of municipalities) could afford to pay a positive price for water at the Great Lakes.

Consequently, the only reasonable market for GRAND Canal water lies with users closer to the Great Lakes[4]. These might be prepared to pay amounts up to about $50 or $100 per thousand cubic metres. The key question is then what quantity of water might conceivably be demanded at that price, since these regions are not affected by drought to the extent suffered by the South-west.

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4 But see Scott (1985) who suggests that if the US government were prepared to pay the exorbitant cost of delivering water to the South-west, it might be willing to pay as much as 100 C$/Ml for make-up water.

Nevertheless, the demand for water in the Great Lakes region is expected to grow. Bruce (1984) suggests an annual growth in consumption of 2.7% per year to 2036. Such a growth rate implies a quadrupling of consumption in 52 years.

Experience with forecasting energy demands suggests that such high growth rates are unlikely to be realized. The IJC considers that projections beyond the year 2000 are too uncertain to use as a basis for planning and policy decisions (1985,31). Table 3 shows that the IJC's own most likely projection is that the rate of water consumption in the Great Lakes Basin will increase to between 161 cubic feet per second (cfs) and 238 cfs. If the willingness-to-pay were $50 per thousand cubic metres and if the increment, 79 cfs, were supplied entirely from James Bay water the total benefits would amount to about $124 million per year. If the consumption increase were twice that predicted by the IJC and if willingness-to-pay were $150 per thousand cubic metres, the total benefits would be $747 million per year. These are the low and high values reported in Table 1.

Stabilization of Water Levels

The second major benefit claimed by proponents of the GRAND Canal is stabilization of the water levels of Lakes Michigan and Huron. Proponents have not cited any studies indicating the order of magnitude of these benefits but at first glance they appear to be low.

Stabilization of Lakes Michigan and Huron would entail using the GRAND Canal to augment natural inflows during times of drought and discharging extra large volumes of water through the various diversions in times of high water. This implies that, in dry seasons, not all the capacity of the GRAND Canal would be available for export beyond the Great Lakes basin. Furthermore, discharge of excess water through the Mississippi River system could cause flood damages and would require preventive engineering works. In short, stabilization of lake levels would seem to imply both an increased variance of water deliveries beyond the Great Lakes and increased costs to water importers. Thus it appears that there would be a trade-off between water export benefits and water level stabilization benefits.

Some idea of the order of magnitude of water stabilization benefits can be obtained from the International Joint Commission's (1983) report on limited regulation of Lake Erie. This report summarizes studies undertaken to determine whether limited regulation of Lake Erie would be in the public interest. Three schemes to increase maximum outflows from Lake Erie were considered. Capacities ranged from 100 to 710 m^3/s. The maximum reduction in maximum Lake Erie levels would be 32 cm and the maximum reduction in range would be 25 cm.

For the largest plan, there would be gains of up to $59 million per year (at 1979 prices and deliberately unspecified currency) in reduced flood damages and gains of up to $68 million per year in improved beach recreation. There would be losses of up to $115 million per year in increased navigation

costs due to lower water levels in shipping channels, losses of up to $24 million per year in reduced power production caused by less efficient use of available water, and losses of up to $35 million to US recreational boating.

It appears, therefore, that the chief benefits to be expected from stabilization of water levels would be first, reduced flood damages and improved recreational opportunities from beaches which are no longer flooded in high water seasons and secondly improved access to recreational boating during dry seasons. Water stabilization would also imply environmental costs, particularly by reducing the intermittent flooding of wetlands.

The IJC study clearly indicates that the benefits of water level stabilization on Lake Erie would be modest. If we take only the positive benefits and adjust to 1985 price levels, we obtain an annual benefit of about $156 million per year. It is not clear how to apply this to Lakes Michigan and Huron which have more shoreline but lower density development. If we double the amount, we still obtain an estimated benefit of only 0.3 billion dollars per year. This is the high estimate reported in Table 1. We take zero as the low estimate.

Power Benefits

A further benefit claimed for the GRAND canal is the generation of hydroelectric power. It should be clear that laws of physics ensure that the scheme will be a net consumer of energy - more energy is required to lift the water to the arctic watershed than can possibly be extracted on the descent. Furthermore, some water will be lost to evaporation on the journey, and hence unavailable for the generation of power. At best we can hope that the power generated in descending will partially offset the power required to lift.

To obtain a rough estimate of the cost savings, suppose that from 50% to 70% of lifting energy can be recovered in downstream generation at a cost of $5.70 per thousand kilowatt-hours. This was the average financial cost of hydraulic power in Ontario, 1984, excluding water rentals. (Ontario Hydro, 1984). Assuming a total pumping energy requirement of 48.9 billion kilowatt-hours per year, the annual cost saving would lie between 0.8 and 1.1 billion dollars, as shown in Table 1.

Since the benefits from hydro generation only partially offset the pumping costs, it would be reasonable to use them to reduce the estimated net cost of the project and to exclude them from the benefit side of the ledger. The present procedure has been adopted purely for expositional reasons.

Employment Benefits

A final category of benefit claimed for the GRAND Canal is the creation of employment. This claim is dubious, since there are two strong arguments for not giving any employment credit to such a program.

First, most economists agree that unemployment levels are determined in the short run primarily by the level of aggregate demand (as influenced by fiscal and monetary policies adopted by the Federal government) and in the

long run by the underlying characteristics of the economy which generate the "natural rate of unemployment". The government may deliberately choose not to reduce aggregate unemployment for fear of stimulating inflation or causing an excessive depreciation of the exchange rate. Under these circumstances it is inconsistent to credit a water project for employment creation while holding back employment creation in the rest of the economy.[5]

Secondly, any large expenditure of money will cause an short run increase in the level of employment. It is inconsistent to credit a project with creating employment without at the same time debiting it for the employment which was lost by not spending funds elsewhere.

These considerations suggest that no project should be given credit for employment creation unless the jobs are created in areas or occupations which have been explicitly designated as targets for government employment creation. Even under these circumstances, one must be very careful not to overestimate the employment created and not to give excessive credit for it.

The employment directly created by a project can often be calculated from estimated labour costs and average wage rates. To this is often added the secondary employment generated by the multiplier effect discussed above. As noted then, multipliers derived from input-output models tend to overstate the multipliers derived from macroeconometric models which incorporate the macroeconomic feedbacks which tend to stabilize the economy. Consequently, the secondary employment effects of a project will be overstated through their use.

Moreover, much of the labour which would be drawn to a project such as the GRAND Canal is not completely unemployed. Only the wages in excess of its current compensation can conceivably be counted as benefits, and even here allowance must be made for premiums such as isolation pay. It might be argued that by employing previously unemployed labour the government reduces its payments of unemployment insurance, but these payments in part reflect whatever utility the unemployed worker derives from his (involuntary) leisure and, in any case, recent work in economics has emphasized that large construction projects may draw workers into a pool of temporary employees who will claim unemployment insurance when they are laid off.

Such arguments suggest that it would be unwise to credit the GRAND Canal with large employment generation benefits. As a rough indicator, one could take an arbitrary fraction of the wage bill to estimate them. We must also make an assumption about the share of labour costs in the total project. In Table 1 it has been assumed that between 5% and 10% of total capital plus operating costs of the project are available as employment benefits. This yields a range of from $0.2 to $2.2 billion per year annualized over the 80 years of the project's life.

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5 A project as large as the GRAND Canal might cause additional problems for stabilization policy by creating inflationary bottlenecks in key industries.

5. Discussion

Reviewing the estimates presented in Table 1, we note that the present value of the quantified benefits from the GRAND Canal scheme ranges between $16.1 billion and $46.3 billion. These benefits are equivalent to an annual flow of between $1.3 and $3.7 billion over the 80 year life of the project. The present value of capital and operating costs is estimated to lie between $121.7 billion and $276.4 billion. Annualized costs lie between $9.8 and $22.2 billion. Possibly important costs remain unquantified. These include the opportunity cost of exported water and the social and environmental costs incurred during construction and operation of the scheme. Thus the quantified costs exceed the benefits by a factor of 6 or 8.

The largest benefits, from power and employment, arise in effect from correcting the price of certain inputs (energy and labour) in calculating net costs. They were treated as benefits largely for expositional purposes. In computing a benefit/cost ratio they might better be viewed as negative costs than as positive benefits. If we take this view than the GRAND Canal project has a benefit-cost ratio in the neighbourhood of 0.07 to 0.15.

These estimates were developed in order to gauge the economic feasibility of the GRAND Canal project and to identify the areas in which further information is most urgently needed. The estimates suggest that the GRAND Canal project is not economically viable. Net Benefits are consistently negative. This conclusion is not dependent upon the particular rate of interest chosen. In computations not reported at length, net benefits were estimated to lie between -93 and -178 billion dollars at a discount rate of 5%, and between -117 and -262 billion at a discount rate of 10%.

This conclusion arises from the limited benefits which flow from the project. Estimated benefits were small for four reasons. First, both the estimated willingness to pay for exported water and the potential volume of exported water were low. Secondly, the losses from flooding and low water on the Great Lakes were estimated to be two orders of magnitude smaller than the estimated costs of GRAND Canal water. Thirdly, care was taken not to confound the economic impact of the project with economic benefits. Finally, only a limited credit was allowed to the project for employment creation.

If further study of this project is undertaken, the most pressing need is to identify a realistic market for the large volumes of water contemplated. Without such a market, additional discussion seems pointless. If, at prices in the order of $100 to $200 per thousand cubic metres, a market for up to 67 billion cubic metres of water per year can be found, then high priority should be placed on refined estimates of the engineering cost of the project. To be taken seriously, the proponents must demonstrate that it might be possible to deliver a specified flow of water to the Great Lakes for combined capital and operating cost in the area of 100 $C/Ml. This is one third the cost estimated in Case 1 of section 3.

Much has been made of the social and environmental costs of a GRAND Canal project. Without much more solid evidence of the financial viability of the scheme, it seems premature to attempt to evaluate these costs with reference to this specific project. Much too little is known, however, about the intrinsic and recreational value of natural waterways and wetlands. A systematic study of these would provide valuable information for the evaluation of other major resource projects as well as studies of the effects of acid precipitation and climatic change.

6. Conclusion

This paper has used a cost-benefit framework to organize a discussion of the economics of the GRAND Canal project. The estimated costs and benefits are very crude. Nevertheless, the exercise has been useful in judging the feasibility of the project and in identifying issues of critical importance.

On the basis of available information, the GRAND Canal scheme seems to be quite unviable. Estimated net benefits are a small fraction of estimated costs, even before quantification of social and environmental costs and the opportunity cost of the water itself. To reverse this assessment would require clear identification of a large potential market for exported water and a well specified engineering plan to deliver the water at costs below those now contemplated.

The cost-benefit framework has proven useful in organizing our discussion and in emphasizing the importance of realistic estimates of potential markets. The techniques developed by cost-benefit analysts have helped in avoiding the misuse of economic impact assessment and in avoiding excessive emphasis on the employment creation aspect of the scheme.

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TABLE 1

SUMMARY OF COSTS AND BENEFITS OF THE GRAND CANAL SCHEME
(in billions of 1986 dollars)

	Annualized		Present Value	
	Low	High	Low	High
BENEFITS				
Quantified				
Consumption Uses	0.1	0.7	1.6	9.3
Stabilization of Great Lakes	0	0.1	0.0	1.2
Power	0.8	1.1	10.0	13.7
Employment	0.5	2.2	6.1	27.6
Total Quantified Benefits	1.4	4.2	17.6	51.9
COSTS				
Quantified				
Capital	7.3	19.1	90.5	237.8
Operating and Maintenance	2.5	3.1	31.2	38.6
Total Quantified Costs	9.8	22.2	121.7	276.4
NET QUANTIFIED BENEFITS	-8.3	-18.0	-104.1	-224.5
NET BENEFIT-COST RATIO				
Net Benefits	0.6	3.1	7.6	38.2
Net Costs	9.0	21.1	111.7	262.7
Benefit-Cost Ratio	0.07	0.15	0.07	0.15
UNQUANTIFIED COSTS				
Opportunity Cost of Water				
Environmental				
Social				
ASSUMPTIONS				
Real Discount Rate	8.0%			
Assumed Lifetime of Project	80 years			
Assumed Construction Period (years	15			

NOTE

Power Benefits have been subtracted from both total benefits and total costs before computing the benefit-cost ratio.

TABLE 2

ESTIMATED CAPITAL AND OPERATING COSTS FOR GRAND CANAL PROJECT

Line	Item	Case 1	Case 2	Case 3
1	Water Diverted (m3/s)	2832	11327	2832
2	Evaporation Losses (percent)	25%	25%	25%
3	Water Delivered to Great Lakes (m3/s	2124	8495.25	2124
4	Water Delivered (Tl/a)	67.0	267.9	67.0
5	Direct Costs			
6	James Bay Containing Dam (G$)	70.0	70.0	
7	Pumping Stations (G$)	14.0	55.8	
8	Conveyance Canal			
9	James Bay to Amos	7.0	10.7	
10	From Amos to Great Lakes	9.1	12.7	
11	Contingency (25% of 6..10)	25.0	37.3	
12	Engineering and Management			
13	5% of 6..11	6.3	9.3	
14	Total Direct Costs	131.4	195.8	50.0
15				
16	Real Discount Rate	8.0%	8.0%	8.0%
17	Construction Period (years)	15.0	15.0	15.0
18	Interest During Construction	106.4	158.6	40.5
19	Future Value of Direct Costs	237.8	354.5	90.5
20				
21	Assumed Life for Amortization	80.0	80.0	80.0
22	Annualized Capital Costs (G$/a)	19.1	28.4	7.3
23				
24	ANNUAL COSTS			
25	Pumping Energy (TWh/yr)	81.5	325.8	81.5
26	Cost per MWh	25.0	25.0	25.0
27	Total Energy Cost (G$)	2.0	8.1	2.0
28	Annual O&M (5% of 22+27)	1.1	1.8	0.5
29				
30	Total Annual Costs	3.1	10.0	2.5
31				
32	TOTAL ANNUALIZED COSTS			
33	in billion $	22.2	38.4	9.8
34	in $/Ml	330.8	143.3	145.7

Case 1: Transmission of roughly 25% of inflow to James Bay
Case 2: Transmission of most of inflow to James Bay
Case 3: Transmission of roughly 20% of inflow to James Bay: Kierans's Capital Cost estimate.

UNITS
Ml Megalitre = 1000 cubic metres
Tl Teralitre = 1 billion cubic metres = 1 cubic km
TWh TeraWatt.hour = 1 billion kWh
G$/a = billion $ per year

SOURCE
Cases 1 and 2: Informal Engineering estimates
Case 3: Elaboration of Kierans (1985) estimate of Capital Cost.

TABLE 3

ESTIMATED CONSUMPTION BENEFITS FOR GRAND CANAL PROJECT

ITEM	LOW	HIGH	NOTE
1 Consumption in year 2000 Great Lakes Basin (cms)	161	238	a
2 Consumption in year 1975 Great Lakes Basin (cms)	82	159	b
3 Predicted Increase, 1975-2000 (cms)	79	79	c
(Gl/a)	2488.5	2488.5	
4 Asssumed Consumption met from James Bay water (Gl/a)	2488.5	4977	
4 Willingness to Pay ($/Ml)	50	150	
(M$/Gl)	0.05	0.15	
5 Total Willingness to Pay (M$/a)	124	747	

NOTES

a IJC (1985, 36)
b IJC (1985, 30)
c 1 cms = 31.5 million cubic metres/annum = 31.5 Gl/a

UNITS

cms cubic metres per second
Ml Megalitre = 1000 cubic metres
Gl Gigalitre = 1 million cubic metres = .001 cubic km
M$/a = million $ per year

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